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DEVELOPMENT OF ENGINEERING DATA ON TITANIUM EXTRUSION FOR USE IN AEROSPACE DESIGN

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J. A. Gottbrath
LOCKHEED-CALIFORNIA COMPANY

TECHNICAL REPORT AFML-TR-67-189

JULY 1967

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DEVELOPMENT OF ENGINEERING DATA ON TITANIUM EXTRUSION FOR USE IN AEROSPACE DESIGN

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FOREWORD

This report was prepared by the Lockheed-California Company, Burbank, California under USAF Contract No. AF 33(615)-5080, "Development of Engineering Data on Titanium Extrusion for Use In Aerospace Design". The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Design Information Development". This work was performed under the direction of Lt. Harold Lachmann and Sidney O. Davis, Project Engineers, Air Force Materials Laboratory, Research and Technology Division.

This report covers work that was conducted between 27 June 1966 and 31 May 1967.

Manuscript released by authors, 31 May 1967.

Work was conducted under the direction of Mr. H. B. Sipple, Department Manager, Materials Engineering. Mr. R. M. Brockett was Engineering Project Leader. Technical consultation was provided by Mr. M. Tiktinsky, Group Engineer Metallic Materials, and by Mr. V. E. Dress and Mr. R. F. Simenz, Research Specialists. Static test programs were conducted under the direction of Miss Judith A. Gottbrath and fatigue testing under the direction of Mr. R. B. Urzi, with overall supervision of test activities by Mr. R. G. Adamson, Group Engineer, Materials Evaluation.

This technical report has been reviewed and is approved.

D. A. Shinn

Chief, Materials Information Branch
Materials Application Division
AF Materials Laboratory

ABSTRACT

Mechanical property data for Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn extruded shapes in annealed tempers were obtained at test temperatures from -110°F to +800°F to provide a base for development of design information for these materials. Data obtained included ultimate tensile strength, tensile yield strength, compressive yield strength, shear, bearing, impact properties, creep, stress-rupture, fatigue, and fracture toughness characteristics.

Separate heats of material in each of the three alloys were obtained from separate suppliers. Two section sizes were obtained from one of the suppliers to provide information on size effects. Tests conducted provided data insofar as practicable within the scope of this program on property variations and on scatter.

Results of testing indicate that with consideration of effect of temperatures used in extrusion processing, extrusions may be utilized in the same manner as titanium materials produced by other methods such as rolling or forging. Data obtained generally indicate that extruded material may be expected to have not only the cost advantages which result from economy of shape design, but will possess advantages in delayed fracture characteristics and creep characteristics when compared with conventional alpha-beta processing of rolled or forged material.

(Distribution of this abstract is unlimited).

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

NOMENCLATURE

TUS	Tensile Ultimate Strength, observed value
TYS	Tensile Yield Strength, observed value
CYS	Compressive Yield Strength, observed value
F_{tu}	Ultimate Tensile Strength, room temperature minimum value
F_{ty}	Tensile Yield Strength, room temperature minimum value
F_{cy}	Compressive Yield Strength, room temperature minimum value
F_{bru}	Bearing Ultimate Strength, room temperature minimum value
F_{bry}	Bearing Yield Strength, room temperature minimum value
F_{sw}	Shear Ultimate Strength, room temperature minimum value
K_{Ic}	Plane Strain Critical Stress Intensity Factor (Fracture Toughness)
K_{Ii}	Sustained load environmental stress intensity limit (Delayed Failure)
A	Ratio of Alternating Stress (Fatigue Tests) to Mean Stress
K_T	Theoretical Stress Concentration Factor
L	Longitudinal
T	Transverse
ksi	Kips (1000 pounds) per square inch
f_{max}	Highest Value of Gross Area Stress
f_{mean}	Mean Gross Area Stress
N	Number of Cycles
R	Ratio of Minimum to Maximum Stress
RT	Room Temperature

Section I

SUMMARY

BACKGROUND

Major increases have occurred in the use of titanium alloy extruded shapes for aerospace applications. These applications include sub-sonic systems operating in conventional environments where advantage is taken of titanium's favorable strength to density relationship and supersonic vehicles where the elevated temperature strength of titanium is exploited.

Today's typical titanium extrusion is produced using billet temperatures such that final working occurs in the beta field with the result that the metallurgical structure differs from that of products such as sheet and plate, bar, or forgings where final processing occurs in the alpha-beta field. The gross titanium extrusion produced, while producing radical savings in material because of closer shape approximation, requires overall machining since tolerances and surface conditions are not suitable for direct application, and since an alpha case on the extrusion must be removed to provide a satisfactory metallurgical surface.

Since the bulk of the present published data on properties of titanium alloys has been determined using rolled sheet and bar material or using forged material with final hot working occurring below the beta transus, this program has been established to provide a base of data from which values necessar for reliable design can be established when analyzed in conjunction with data from other sources.

MATERIALS

Annealed material in each of three alloys, Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn was obtained from two vendors for analysis. The thin tee section, Figure 1, was supplied by both vendors to provide data on effect of heat and source on test results. A heavier section, Figure 2, was also obtained in each alloy from one of the vendors in order to probe size effect on annealed extrusions, and in order to expand the data base.

TEST OBJECTIVES

Mechanical property tests were conducted with the Ti-6Al-4V, Ti-8Al-1Mo-1V, and Ti-6Al-6V-2Sn extrusions at temperatures ranging from -110°F to 800°F. Tests included tensile and compressive property determinations, shear and bearing, creep and stress rupture, fracture and delayed failure properties, impact properties, and fatigue characteristics.

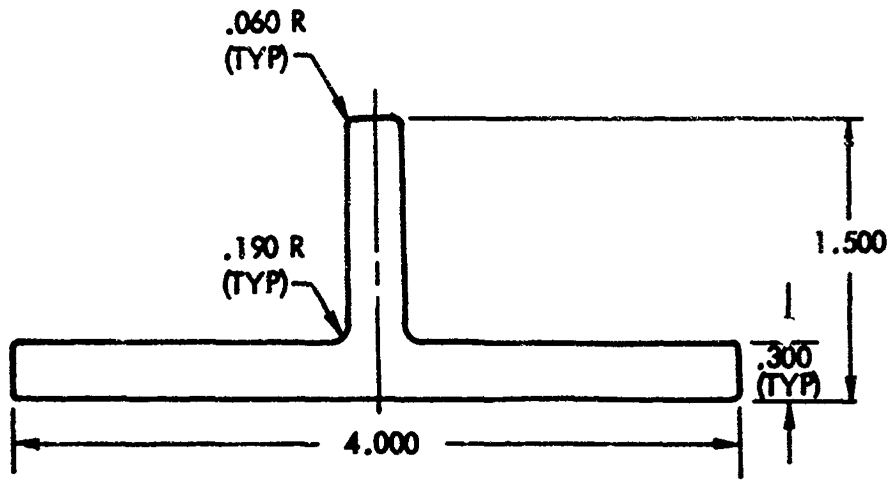


Figure 1. Thin Extrusion

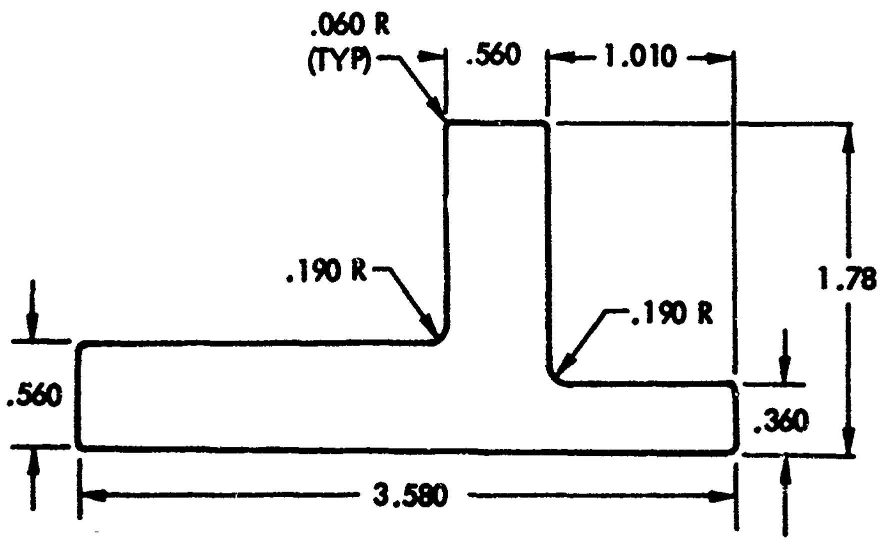


Figure 2. Thick Extrusion

TEST RESULTS

Orientation of testing and analysis of data has been directed in such manner as to define relative advantages and limitations of extruded materials in comparison to competitive alternates. Presentation has been directed toward development of MIL-HDBK-5 data when supplemented by data from other sources.

Room temperature tensile and compressive properties were analyzed to establish that properties are uniform within a piece, including cross-section location and position in length. Variations between vendors could not be evaluated on a meaningful basis within scope of this program, but can be determined from vendor test statistics. Present specification values accepted by producers are consistent with those offered for other product forms with the exception of elongation and reduction of area.

The effect of temperature on properties appeared to reflect a consistent relationship between vendors and heats.

The extruded product, with its beta worked structure appears to offer advantages in resistance to delayed failure (Figure 3), and in resistance to creep (Figure 4).

Properties of the alloys followed normal patterns, alloy Ti-6Al-6V-2Sn showing highest strengths, while Ti-8Al-1Mo-1V possessed best toughness and the highest tensile modulus. Comparative typical ultimate tensile strengths, tensile yield strengths and compressive yield strengths are shown in Figures 5, 6, and 7. Ti-6Al-6V-2Sn showed lower resistance to creep at elevated temperatures than the other alloys. Comparative resistance to creep of the three materials under rapid heat-rapid load test conditions is shown in Figures 8 and 9.

Ti-6Al-6V-2Sn provides the highest level of strength at any of the temperatures investigated. As an annealed product, it furnishes strength levels comparable to an intermediate level of Ti-6Al-4V heat treated and aged. Ductility and toughness are generally considered to be inferior to the other two alloys, Ti 6Al-4V and Ti-8Al-1Mo-1V. At elevated temperatures Ti-6Al-6V-2Sn appears more sensitive to creep than the other two materials but none appear to be creep limited at anticipated operating temperatures. Effect of elevated temperature on this alloy seems less severe than effect on the other two alloys.

Ti-8Al-1Mo-1V possesses favorable modulus and favorable density values. Toughness of this alloy appears excellent. Delayed failure characteristics of Ti-8Al-1Mo-1V appear unfavorable however, as shown in Figure 3, and have limited consideration of Ti-8Al-1Mo-1V for applications in general airframe use. The elevated temperature properties, particularly resistance to creep in hot areas, indicate possible specialized usages particularly suitable to Ti-8Al-1Mo-1V.

Ti-6Al-4V provides a good combination of strength, toughness not offered by Ti-6Al-6V-2Sn and environmental resistance. These qualities, coupled with production reliability and low cost tend to make this the present preferred alloy

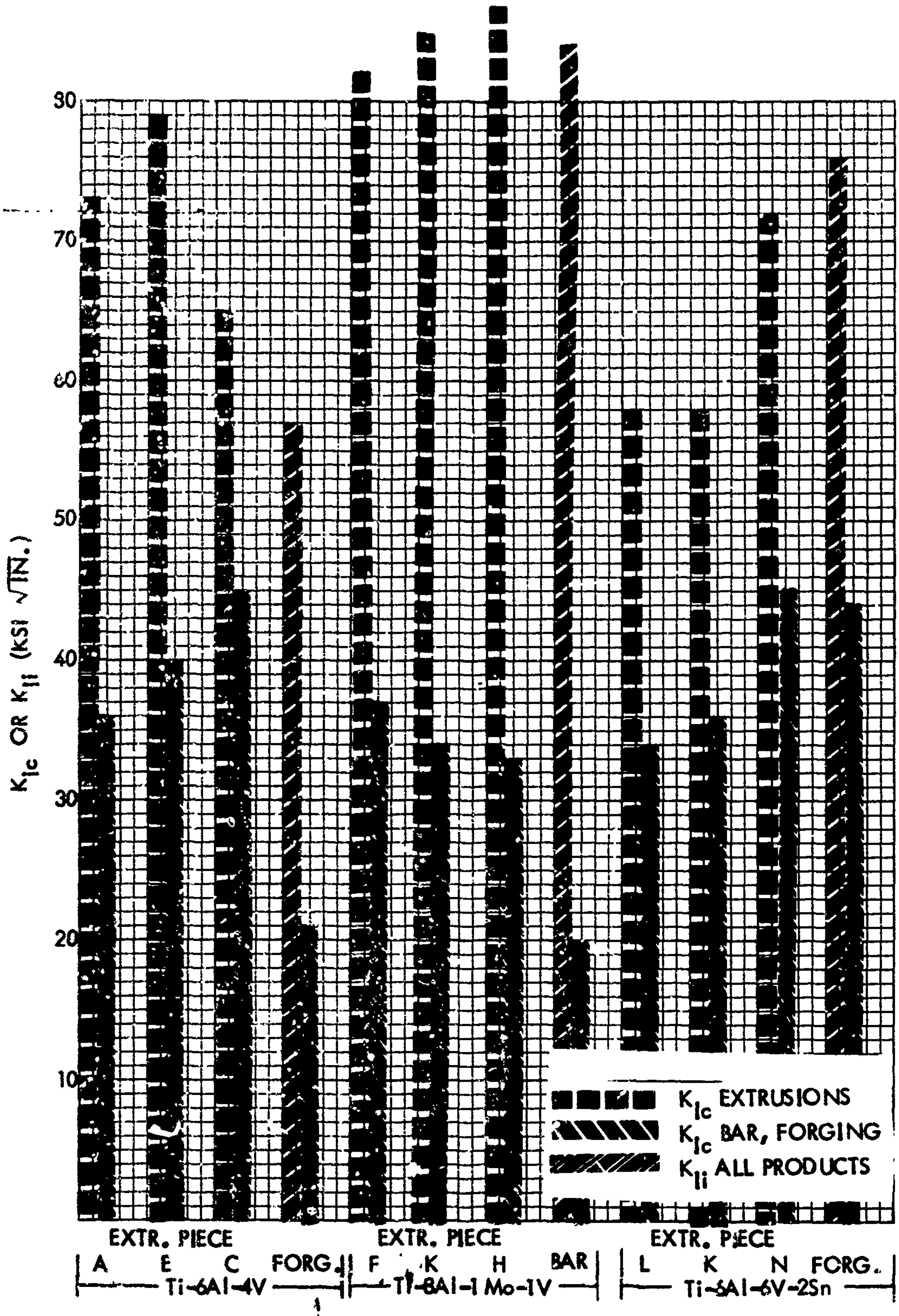


Figure 3. Comparison of Typical Fracture Toughness and Delayed Failure Characteristics of Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn Extrusions, and Typical Forgings and Bar

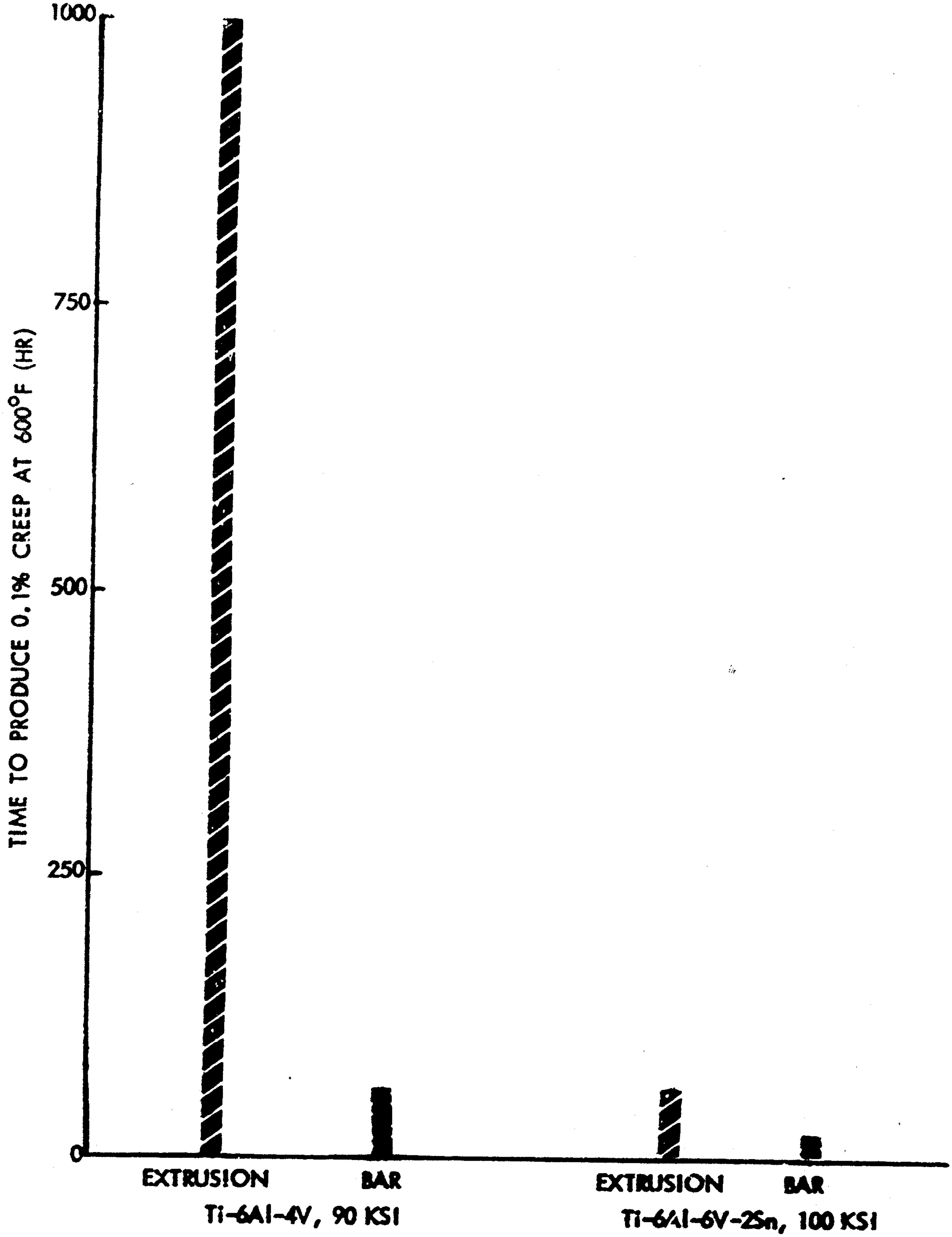


Figure 4. Comparative Creep Characteristics Extrusions and Bar, Typical Data

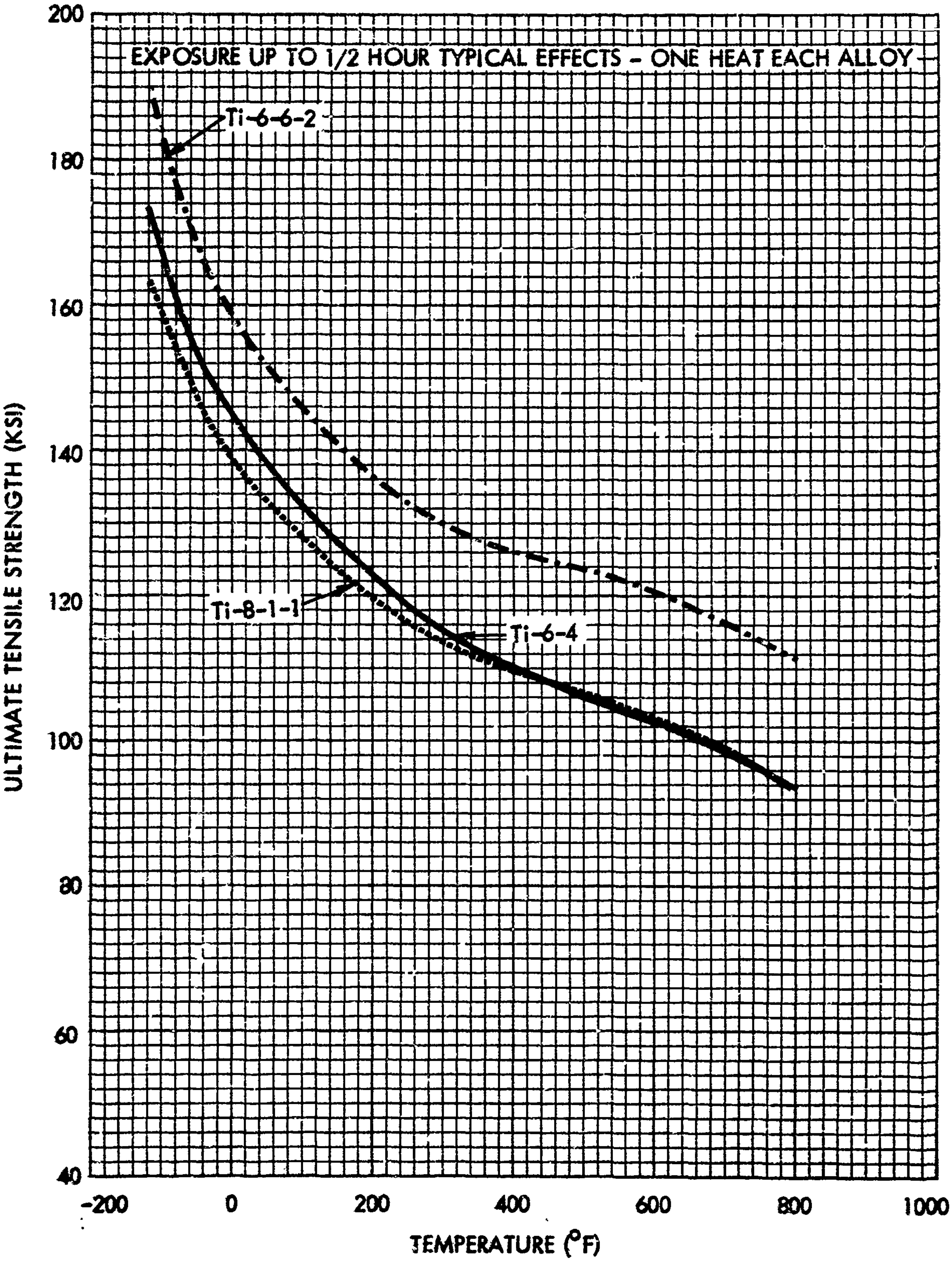


Figure 5. Comparison of Typical Ultimate Tensile Strengths of Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn Extrusions at Various Temperatures

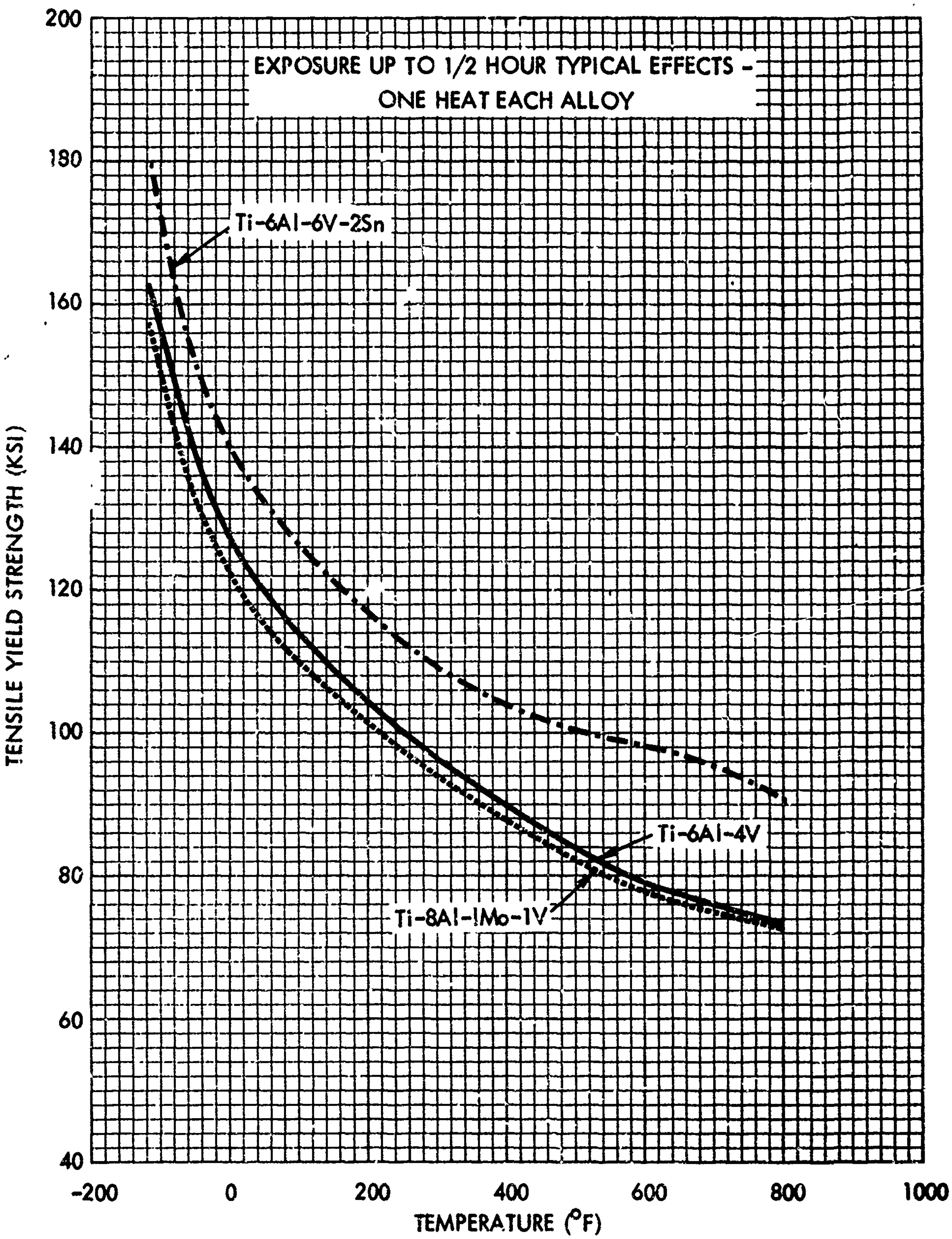


Figure 5. Comparison of Typical Tensile Yield Strengths of Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn Extrusions at Various Temperatures

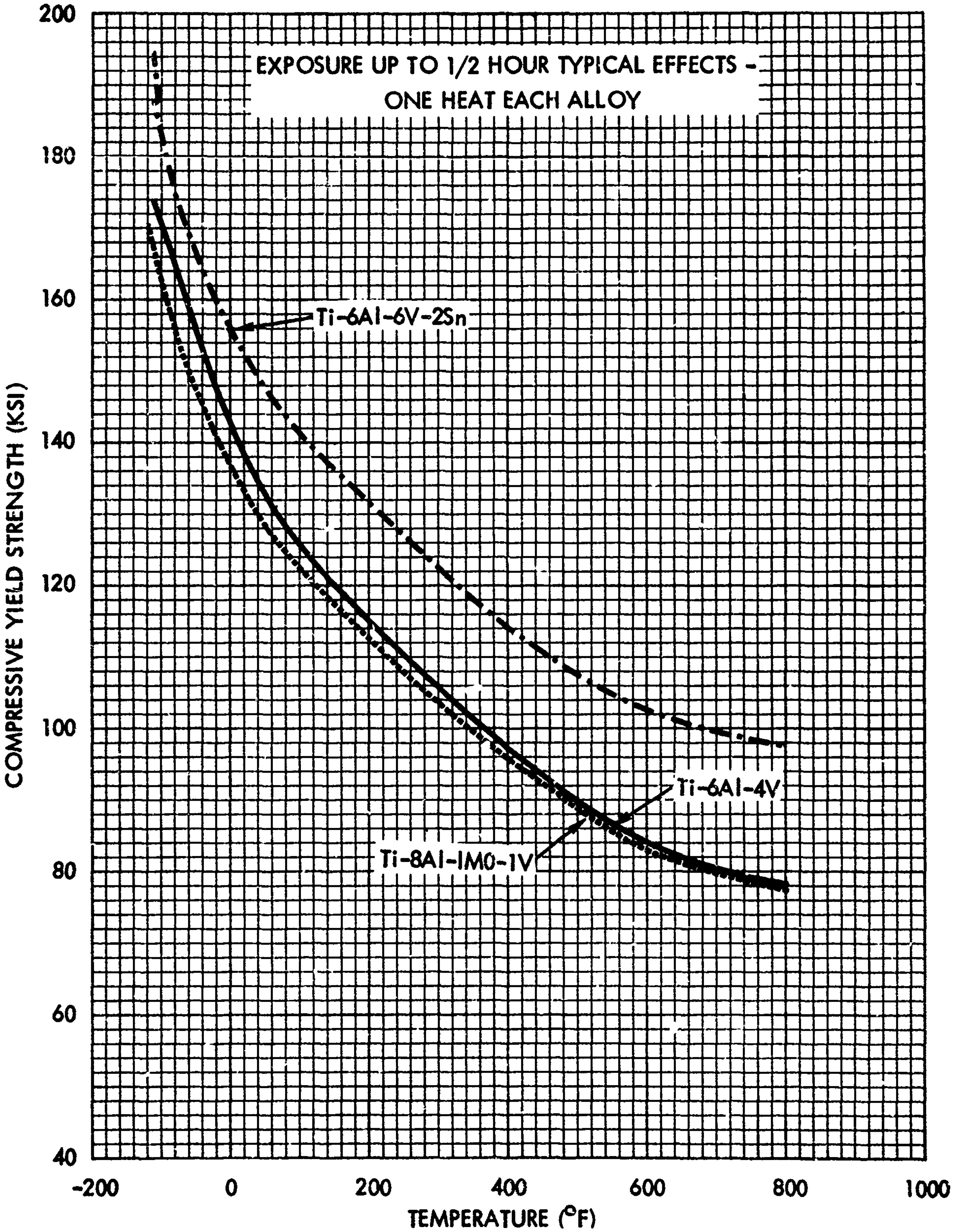


Figure 7. Comparison of Typical Compressive Yield Strengths of Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn Extrusions at Various Temperatures

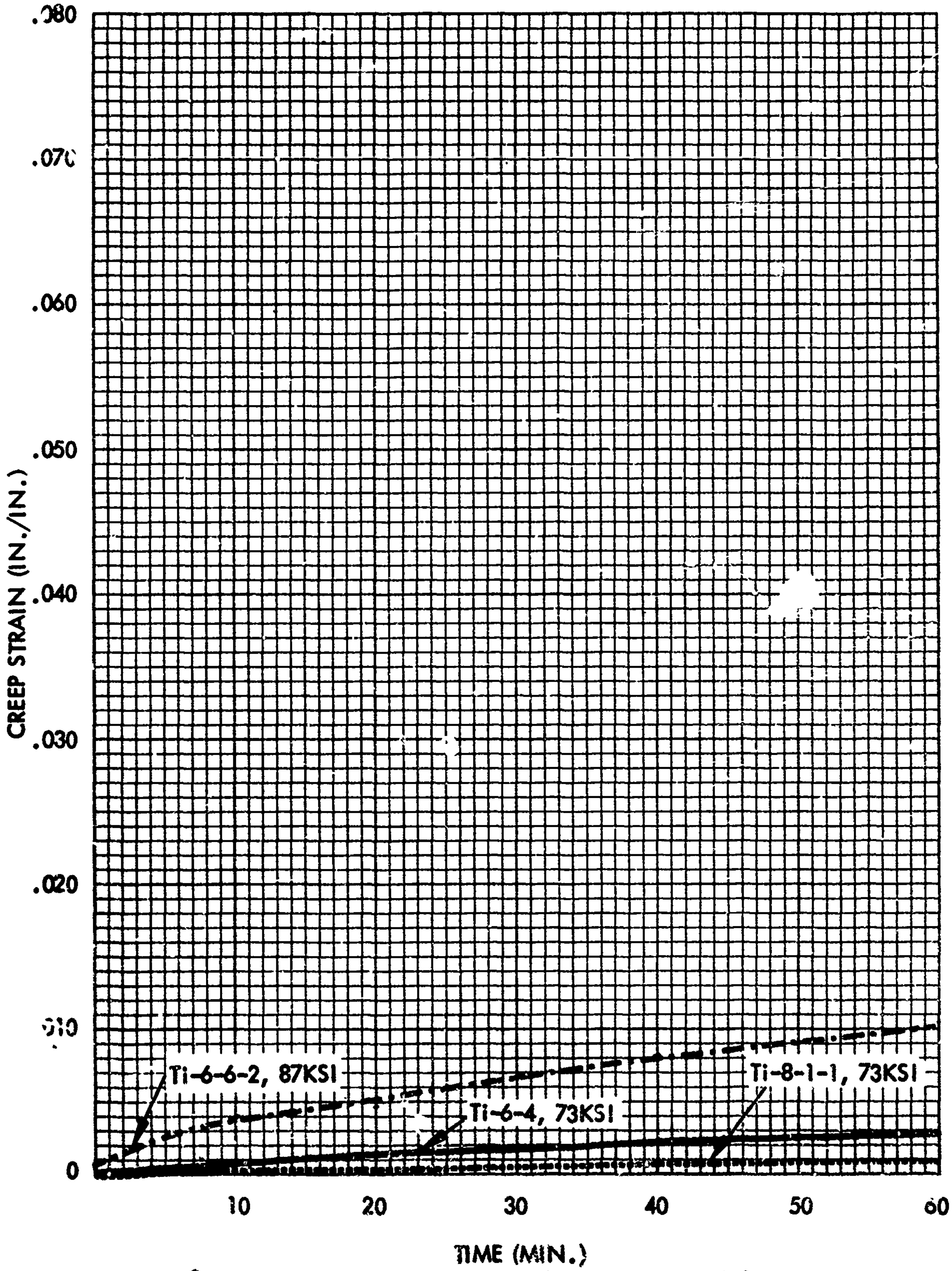


Figure 8. Comparative Short Time Rapid Heat and Load Creep Characteristics at 800°F Yield Strength

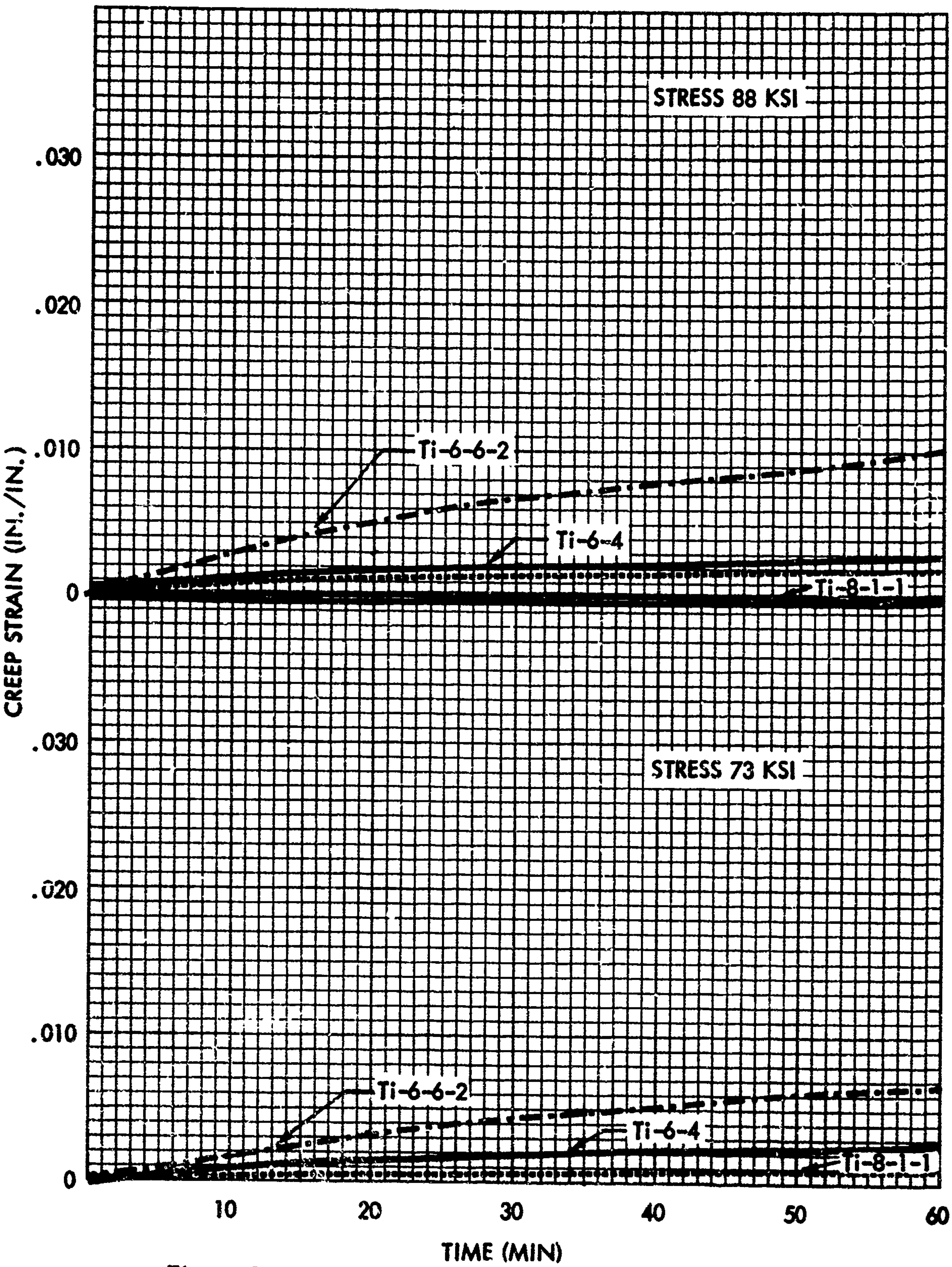


Figure 9. Comparative Short Time Rapid Heat and Load Creep Characteristics at 800°F

choice except for instances where requirements dictate exploiting the special peculiarities of the other alloys.

Within overall data compilations, the fatigue characteristics of the three alloys appear comparable. Figure 10 compares typical fatigue characteristics at various lives.

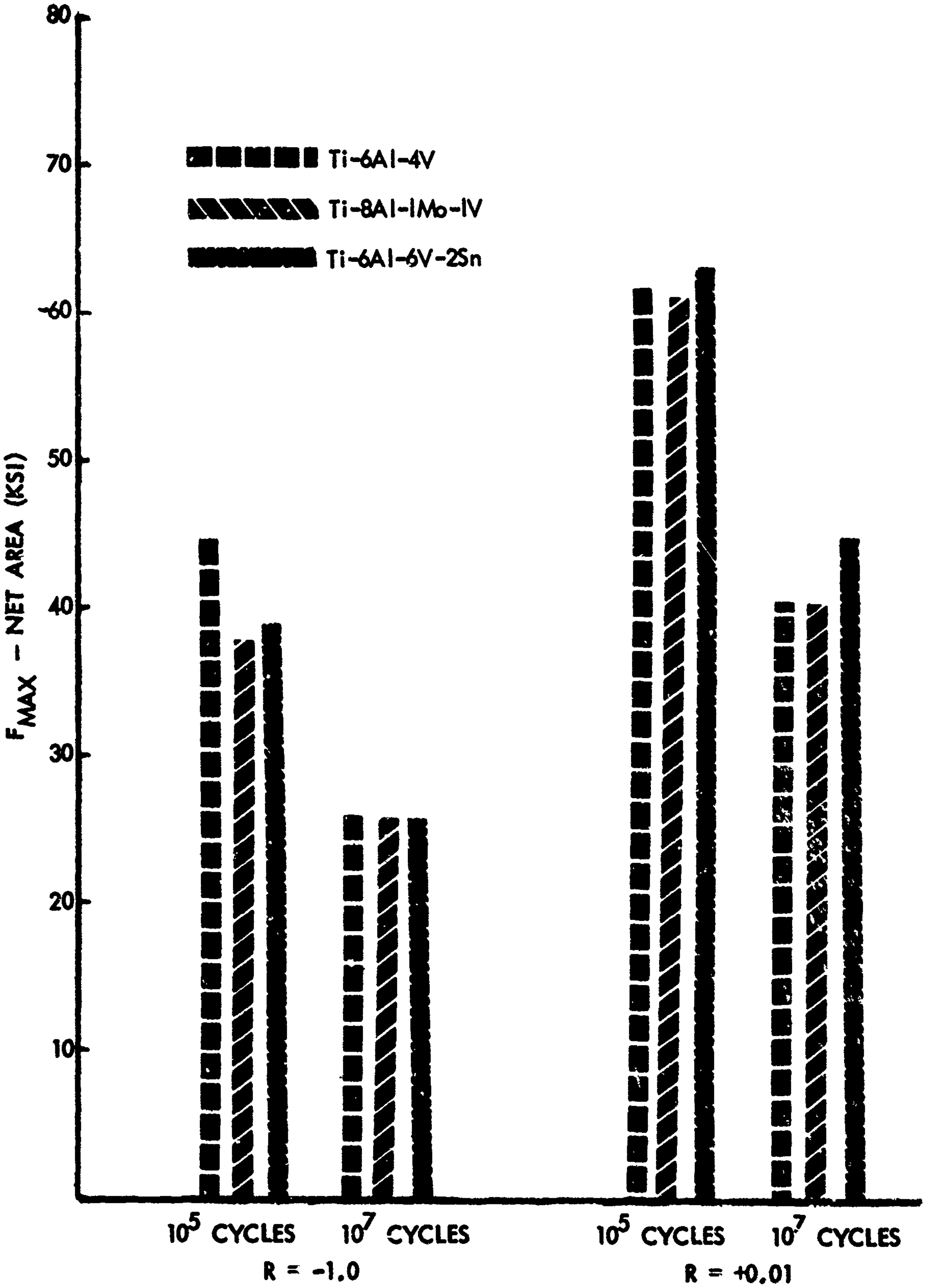


Figure 10. Comparative Maximum Stresses for 10^5 and 10^7 Cycles for Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn Extrusions Typical Values, Room Temperature, $K_T = 2.76$

Section II

MATERIAL

BACKGROUND

Billet temperatures used in the extrusion of titanium alloy shapes are typically above the beta transus of the material - at temperatures which result in a metallurgical structure which differs markedly from that of other product forms such as sheet and plate, rod and bar, and forgings which normally have a final work in the alpha-beta field. Reduction ratios used in extrusion are higher than those used in other product types, and cooling in air occurs quite rapidly. Because of these, and other basic differences in the manufacturing processes, it has been necessary to establish material properties specifically for titanium extrusions.

MATERIALS PRODUCERS

Material for testing in this program was extruded by Harvey Aluminum, Torrance, California, and by the H.M. Harper Company, Morton Grove, Illinois. Harvey supplied both the thin extrusion, Figure 1, and the thick extrusion, Figure 2. Harper supplied material in the thin configuration only. Processing procedures used by the two producers were similar, except Harper utilized hot stretching as a standard straightening procedure, while Harvey utilized other straightening techniques.

HEAT TREATMENTS

Heat treatments used in these evaluations were selected to be generally applicable and acceptable in aerospace design, offering high levels of fracture toughness and resistance to delayed failure in salt water.

Since the present program was designed to test one heat treatment type only in each of the three alloys, annealed tempers were selected as being most representative for present use.

Annealing temperatures selected correspond with the standard temperatures shown for the alloys in MIL-H-81200, and in other standard industry documents. The soaking time at temperature was established with consideration of the section thicknesses involved. Air cooling from the annealing temperature to room temperature was used, since normally toughness characteristics with this processing are superior to those obtained with slow furnace cooling through part of the temperature range. For example, an extruded shape in Ti-6Al-4V tested in another program showed delayed fracture property (K_{Ii}) of 46 ksi for air cooled material and 31 ksi for material from the same extrusion annealed and furnace cooled to 1000°F. Straightening after annealing was restricted to

avoid any residual Bauschinger effect. Time and temperature relationships are such that values obtained coordinate closely with existing producer data. Heat treatment schedules are shown below.

HEAT TREATMENT SCHEDULE

Alloy	Temperature ($\pm 25^{\circ}$)	Time	Cooling
Ti-6Al-4V	1300°F	40-60 Min.	Air cool to room temp.
Ti-8Al-1Mo-1V	1450°F	40-60 Min.	Air cool to room temp.
Ti-6Al-6V-2Sn	1300°F	40-60 Min.	Air cool to room temp.

Application of data from this program, and comparisons made with other data must be predicated on generally comparable heat treatment schedules.

PROCESSING DATA

Material from Harvey was cast as a 24-inch diameter ingot by the Consumable Electrode Vacuum Melt process by the Special Metals Division of Harvey Aluminum. The 24-inch ingot was forged to furnish a lathe turned six-inch billet diameter for the thin extrusion (pieces A, B, F, G, L, M) and a seven-inch diameter for the heavy extrusion (pieces E, K and R).

Billet used by Harper for the Ti-6-4 extrusion (pieces C and D) and the Ti-6-6-2 extrusion (pieces N and P) was obtained from Reactive Metals Inc. Material was cast as a 30-inch diameter ingot by the Consumable Electrode Vacuum Melt process, forged to approximate billet size and lathe-turned to the 6 3/4-inch diameter used. The Ti-8-1-1 billet for pieces H and J were obtained from Titanium Metals Corporation. A twenty-eight-inch CEVM billet was forged and supplied lathe-turned to 6 3/4-inch round.

Chemical composition of the material used is shown in Table I.

Extrusions from Harvey Aluminum were produced on a Loewy 3850 ton horizontal extrusion press. Extrusions from H. M. Harper were produced on a Loewy 1650 ton horizontal extrusion press, modified to provide approximately 1800 tons of pressure. Details of processing are shown in Table II.

Straightening by Harvey was performed before the annealing operation. Harper produced material was straightened by a hot stretch after the anneal. Temperatures for hot straightening at Harper were monitored by thermocouples attached to the length being straightened. To avoid warpage, parts were cooled in the stretcher with a low stress level held and automatically monitored. The two variations outlined represent the two common practices being followed in extrusion production. With proper control of straightening temperature, amount of stretch, and control of relief of strain during cooling

TABLE I CHEMICAL COMPOSITION OF TEST EXTRUSIONS

Extruder Piece Ident.	Billet Source, Heat	Chemical Analysis in Weight Percent									
		Al	V	O	N	C	Fe	H (PPM)	Mo	Sn	Cu
Ti-6-4											
Harvey, A,B	Harvey D 47	6.31	4.32	0.15	0.009	0.039	0.18	43			
Harvey, E	Harvey D 79	6.40	4.38	0.17	0.011	0.044	0.19	60			
Harper, C,D	Reactive 301658	6.6	4.3	0.165	0.008	0.02	0.17	59			
Ti-8-1-1											
Harvey F,G	Harvey 3263	7.82	1.04	0.11	0.014	0.024	0.26	49	1.00		
Harvey K	Harvey B 40	8.10	1.15	0.13	0.006	0.026	0.23	63	1.10		
Harper H,J	Timet D-9399	7.9	1.1	0.080	0.008	0.023	0.06	60	1.0		
Ti-6-6-2											
Harvey L,M	Harvey B 16	5.75	5.72	0.17	0.013	0.097	0.68	62		1.82	0.72
Harvey R	Harvey E 33	5.85	5.49	0.13	0.008	0.071	0.71	88		2.18	0.72
Harper N,P	Reactive 292557	5.7	5.7	0.132	0.008	0.02	0.72	0.43		2.1	0.69

TABLE II EXTRUSION PROCESSING HISTORY

Producer	Alloy	Section	Nominal Container Diameter	Extrusion Ratio	Billet Temperature	Runout (Approx.)	Straightening	Cleaning
Harvey	Ti-6-4	Fig. 1	6"	20.0	1980°F	26'-6"	Arbor Press before anneal	Kolene descale (850°F 1 hour) Pickle (HNO_3-HF)
		Fig. 2	7"	16.9	1970°F	23'		
	Ti-8-1-1	Fig. 1	6"	20.0	2085°F	27'		
		Fig. 2	7"	16.9	2070°F	23'		
	Ti-6-6-2	Fig. 1	6"	20.0	2100°F	27'		
		Fig. 2	7"	16.9	2010°F	23'		
Harper	Ti-6-4	Fig. 1	7"	23.8	2120°F	26'	Hot stretch after anneal, stretch performed at anneal temperature	Abrasive blast clean to descale Pickle (HNO_3-HF)
	Ti-8-1-1	Fig. 1	7"	23.8	2120°F	26'		
	Ti-6-6-2	Fig. 1	7"	23.8	2120°F	26'		

no significant difference appeared in end results when hot straightening after anneal was compared with the final operation being the anneal cycle.

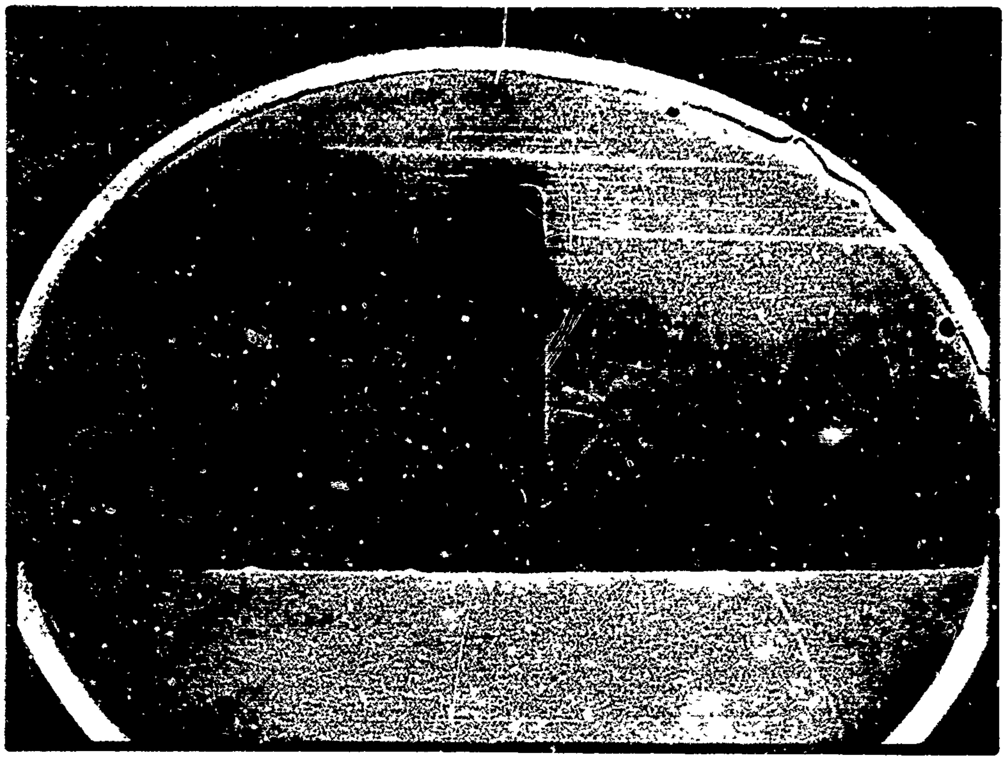
METALLOGRAPHIC CONTROL

Two transverse sections were examined for each of the five lengths of extrusion in each of the three alloys. Specimen location was at the end inch of each piece.

In general, macrostructures exhibited end grain, with little evidence of grain flow. Those lines which occurred followed the contour of the section. Grain size appeared largest at the center or junction of the tee, and was finer in the leg areas. The thinner leg of the unequal thickness tee showed smaller grains than in heavier areas, as would be expected from the degree of work during extrusion.

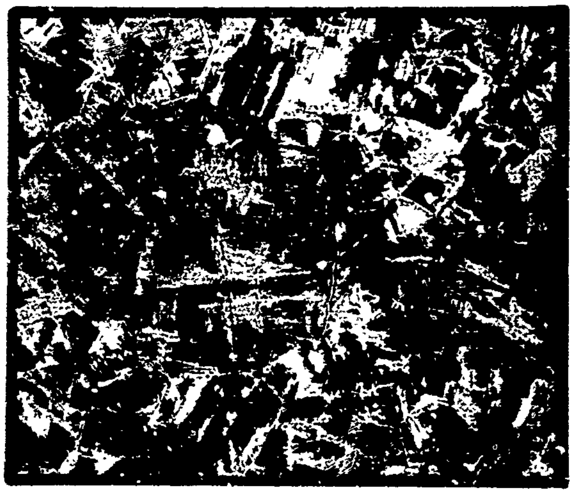
Microstructures of the extrusions are considered to be characteristic of those of titanium alloys extruded above the beta transus temperature.

Typical photomicrographs and photomacrographs for Ti-6Al-4V are shown in Figure 11, for Ti-8Al-1Mo-1V in Figure 12 and for Ti-6Al-6V-2Sn in Figure 13.



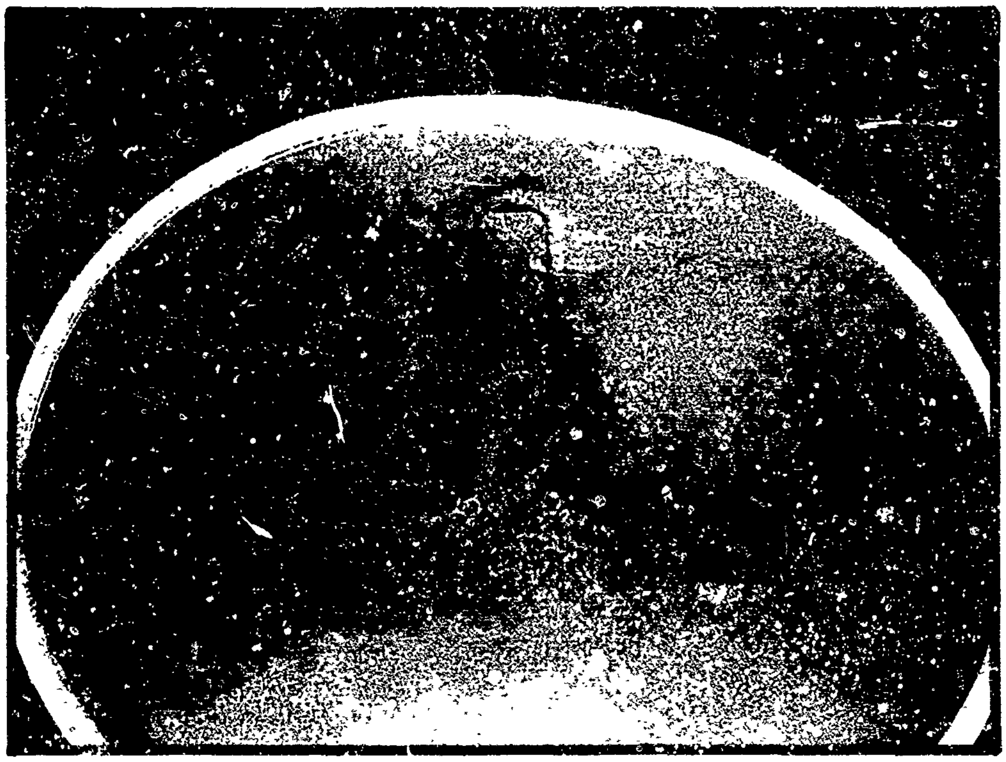
Macrostructure (1-1/2x)

Microstructure, Junction (200x)



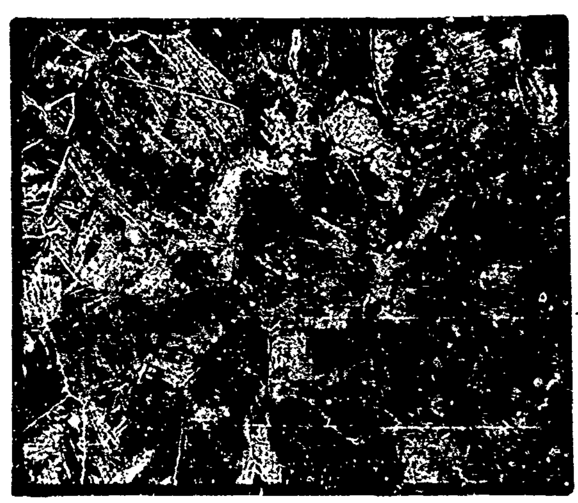
Microstructure, Cap Tip (200x)

Figure 11. Typical Macrostructure and Microstructure of Ti-6Al-4V Extrusion



Macrostructure (1-1/2x)

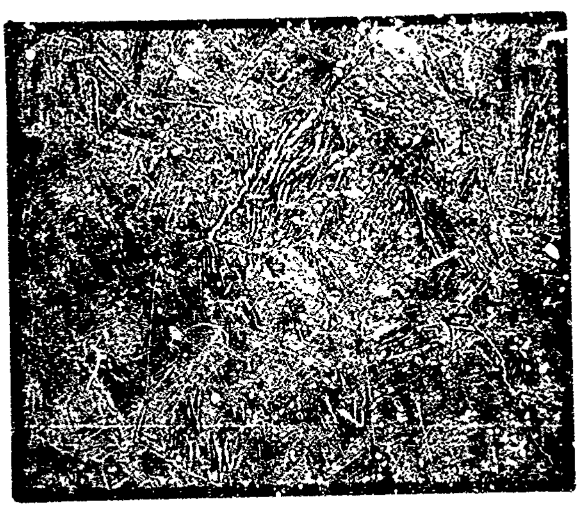
Microstructure, Junction (200x)



Microstructure, Cap Tip (200x)

Figure 12. Typical Macrostructure and Microstructure of Ti-8Al-1Mo-1V Extrusion

Macrostructure (1-1/2x)



Microstructure, Junction (200x)

Microstructure, Cap Tip (200x)

Figure 13. Typical Macrostructure and Microstructure of Ti-6Al-6V-2Sn Extrusion

Section III

MATERIAL PROPERTY TEST PROCEDURES

TENSILE TESTS

The specimens used in the tensile tests are shown in Figures 14 and 15. The standard 1-inch gage length flat specimen was used to test the small extrusions; the standard 1-inch gage length round specimen was used to test the large extrusions. The tests were conducted in 5, 50, and 120 Kip Baldwin universal test machines, in accordance with the requirements of FED-STD-151. A strain rate of 0.005 in/in/min was used through the proportional limit of the material. Class B extensometers were used in conjunction with standard autographic readout equipment to provide partial or full length load-strain curves.

COMPRESSION TESTS

The Lockheed standard X-6720-8 specimen used in the compression tests is shown in Figure 16. The tests were conducted in 5, 50, and 120 Kip Baldwin universal test machines at a strain rate of 0.005 in/in/min through the proportional limit of the material. Class B extensometers were used in conjunction with standard autographic readout equipment to provide load-strain curves.

TENSION AND COMPRESSION MODULUS OF ELASTICITY

The tension and compression modulus of elasticity tests were conducted on the specimens shown in Figures 15 and 16 in a Research Inc. 100 Kip closed loop servo-hydraulic materials testing system. The precision strain data for modulus determination were obtained using Tuckerman optical strain gages. Each specimen was loaded in a minimum of five equal load increments to a maximum stress that was below 50 percent of the nominal yield strength of the material. A Tuckerman gage was attached to each side of the specimen, and the strain was recorded for each gage at each load increment. The strain readings were plotted on graph paper, and a straight line between the points was drawn to provide a slope value for determination of the modulus value for each gage. If the modulus values for the two gages varied less than two percent, the average of the two values was reported as the modulus of elasticity for the specimen. If the two values varied by more than two percent, the specimen was retested using the same procedure until the results obtained varied by less than two percent.

SHEAR TESTS

The specimen used in the shear tests is shown in Figure 17. Double shear type tests were conducted in an 120 Kip Baldwin universal test machine using standard clevis and tongue fixtures. The load was applied at a rate which corresponded to a head deflection rate of 0.1 inch/min; only the ultimate load was recorded.

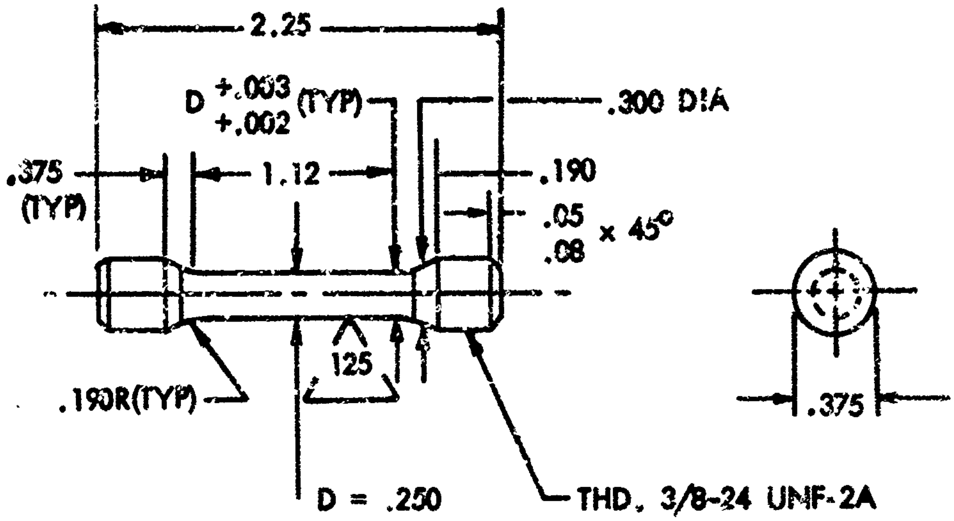


Figure 14. Round Tensile Specimen

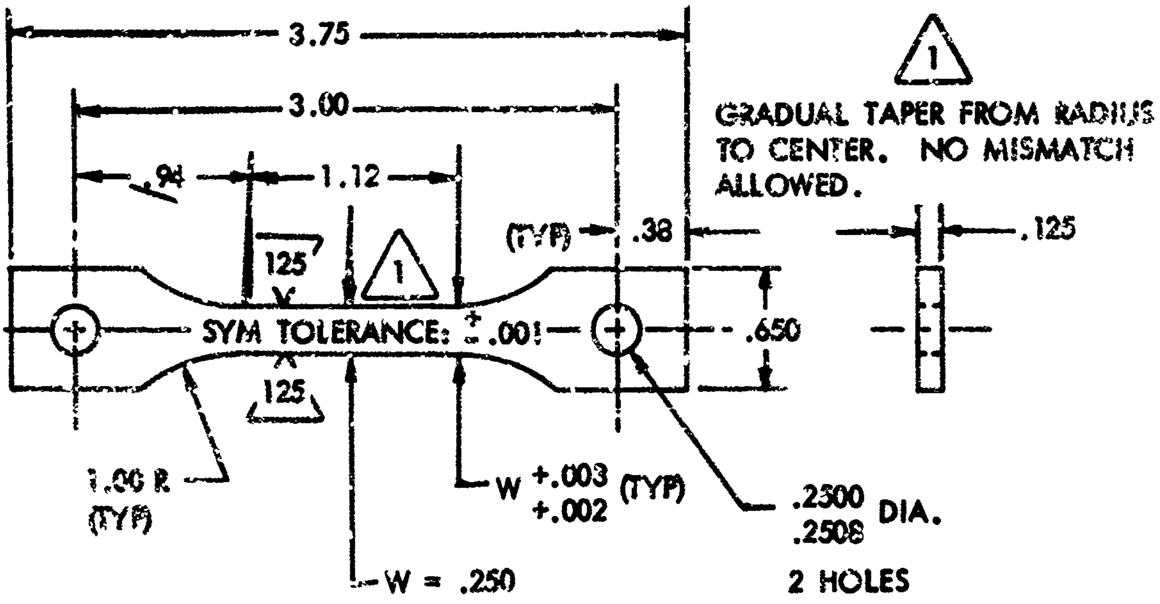


Figure 15. Flat Tensile Specimen

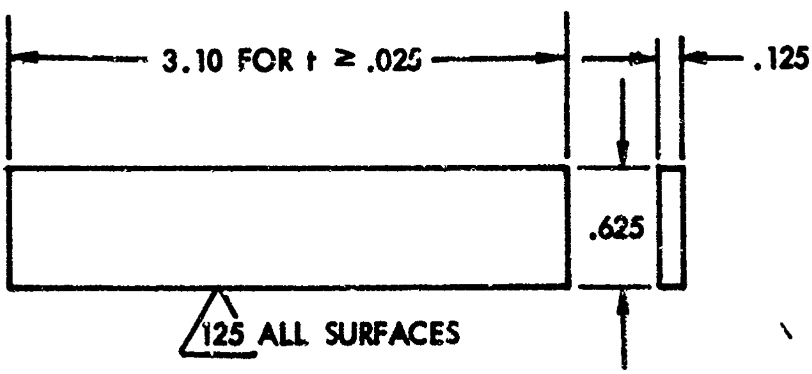


Figure 16. Compression Specimen

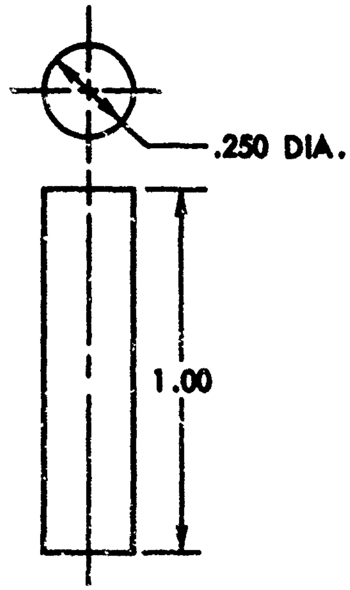


Figure 17. Shear Specimen

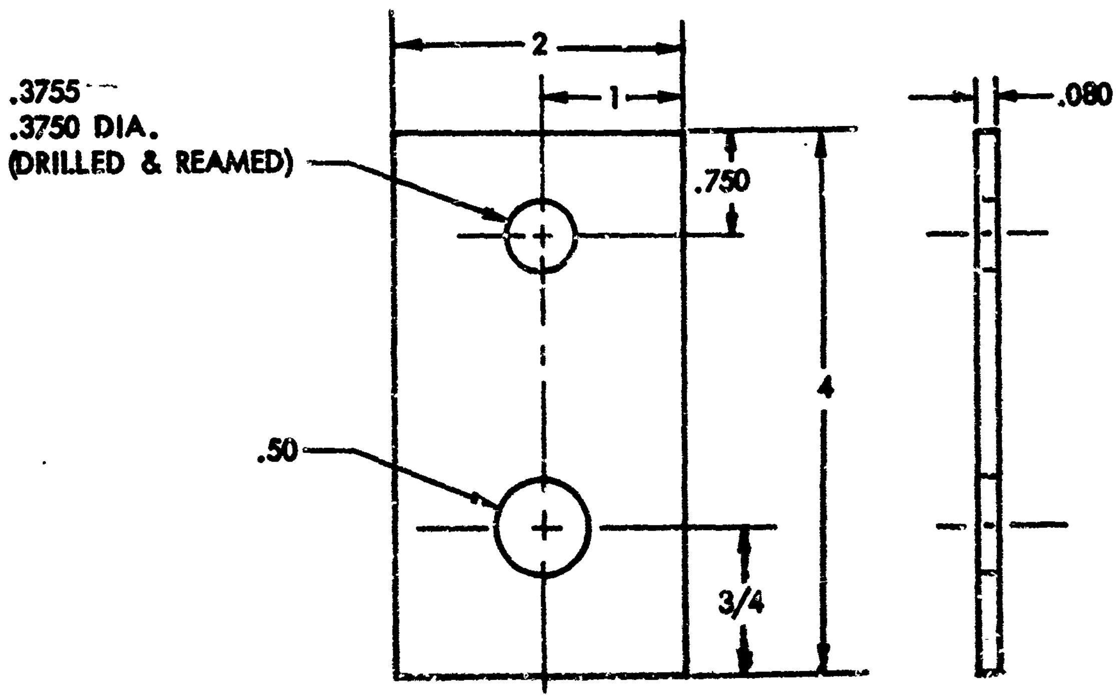


Figure 18. Bearing Specimen

Misalignment of some of the specimens in the fixtures resulted in certain failures occurring through single shear after extensive bending had taken place. The single shear values were lower than the double shear values for comparable specimens and were considered invalid. Data patterns establishing other test points were considered sufficiently significant, however, that duplicate testing was not considered to be required.

BEARING TESTS

The bearing tests (e/D = 2) were conducted on the specimen shown in Figure 18. The bearing hole was drilled and reamed to within one-thousandth of an inch of the diameter of the hardened steel loading pin. The tests were conducted in a 120 Kip Baldwin universal test machine at a rate corresponding to a test head movement rate of 0.008 in/min through the yield point of the material. A load-strain curve was obtained for each specimen by means of a Class B extensometer in conjunction with standard autographic readout equipment. The yield strength was calculated by using the load at which the recorded permanent deformation, using the offset method, Δ was equivalent to 2 percent of the hole diameter.

For the e/D = 1.5 tests, the bearing specimen was modified so that the edge distance was reduced from 0.750 to 0.562 inch. The test procedure remained the same.

TEMPERATURE EFFECT TEST PROCEDURES

The test procedures for the tension, compression, shear, and bearing tests were essentially the same for each test temperature between -110° and $800^{\circ}F$. The $-110^{\circ}F$ tests were conducted in a gaseous CO_2 test chamber; the elevated temperature tests were conducted in a circulating air furnace. The specimens were held at the test temperature for 20 minutes before testing. Both the test chamber and the specimen were monitored by thermocouples, and the test temperature of the specimen was maintained at the specified level $\pm$ $5^{\circ}F$.

CREEP AND STRESS RUPTURE TESTS

Standard creep and stress rupture tests were conducted on the specimen shown in Figure 19 at 400, 600 and $800^{\circ}F$ in accordance with ASTM Specification E-139. The tests were conducted in 6 or 12 Kip Satec creep machines. A thermocouple was attached to each end of the specimen gage length and a temperature-time plot was recorded throughout the test. A LVDT extensometer was used to continuously record a time-strain plot.

After initial probes, stress rupture tests were discontinued if rupture did not occur within a time of at least 100 hours. The creep tests were discontinued after 1000 hours, or in some cases after a shorter period of time if the specimens were not undergoing creep deformation.

Because of the apparent resistance of the extruded metallurg[illegible] structure to creep deformation, a portion of the testing was re-directed [illegible] at rapid heating-rapid loading creep could be probed.

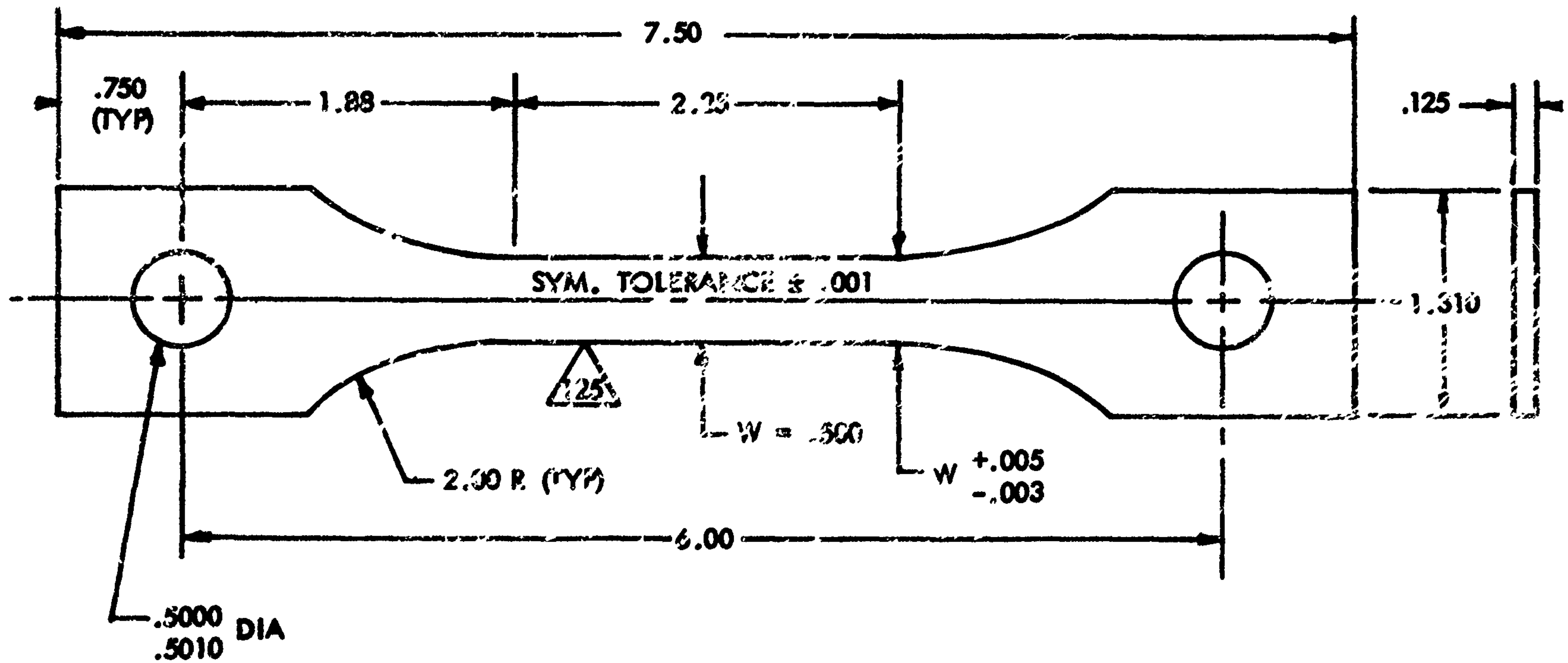


Figure 19. Creep and Stress Rupture Specimen

The short time creep tests were conducted at 600°F and 800°F on the remainder of the specimens under conditions of rapid heating. The tests were conducted in accordance with ASTM Specification E-150 using loading condition (1). Tests were conducted in a Research Incorporated 100 Kip test machine using the self-resistance method of heating. The specimen was heated to the test temperature ± 10°F in 60 seconds and held at the nominal test temperature for 60 seconds prior to application of the load. The temperature was monitored by thermocouples attached to the ends of the specimen gage length.

The load was applied at a uniform rate within 5 ± 2 seconds from the time of start of loading. Strain measurements were obtained using a Class B extensometer. Strain was recorded from the start of heating of the specimen until the specimen was unloaded.

CHARPY IMPACT TESTS

The standard Charpy V-notched specimen shown in Figure 20 was used to test the large extrusions; the modified specimen shown in Figure 21 was used to test the small extrusions. The tests were conducted at -110, 72, 110, and 400°F in accordance with Method 221.1 of Federal Test Method Standard No. 151.

PLANE-STRAIN FRACTURE TOUGHNESS

Edge cracked, four point loaded constant moment bend specimens were used for the fracture toughness tests. The 1-inch wide specimen shown in Figure 22 was used to test the large extrusions; the 1/2-inch wide specimen shown in Figure 23 was used to test the small extrusions. A fatigue crack was generated at the base of the machined vee notch by repeated tension-tension loading in four point bending. The ratio of minimum to maximum load was 0.1; the maximum nominal bending stress level used was less than 50 percent of the tensile yield strength of the material. The total crack depth ("vee" notch plus fatigue crack) was nominally 20 percent of the specimen width.

The pre-cracked specimens were loaded to failure in the 100 Kip test machine at a rate equivalent to a strain rate of 0.005 in/in/min. A model PD-1M deflectometer was used to obtain an autographic curve of load vs. test head movement. The "pop-in" load (point of initial crack instability) was obtained from the curve, and the crack depth was measured on the specimen fracture surface. These values were used in the following equation to obtain the plane-strain fracture toughness value K_{Ic} (the critical stress-intensity factor associated with initiation of unstable plane-strain fracturing). The units for the K_{Ic} value are Ksi $\sqrt{in.}$

$$K_{Ic}^{\ 2} = \frac{P^2 L^2}{(1-\mu^2)\ B^2 W^3} \quad 34.7 \left(\frac{a}{W}\right) - 55.2 \left(\frac{a}{W}\right)^2 + 196 \left(\frac{a}{W}\right)^3$$

where:

P = load at crack instability, (Kips)

L = moment arm length (Inches) (3 in. for the 1-inch wide specimen and 3/2 in. for the 1/2-inch wide specimen)

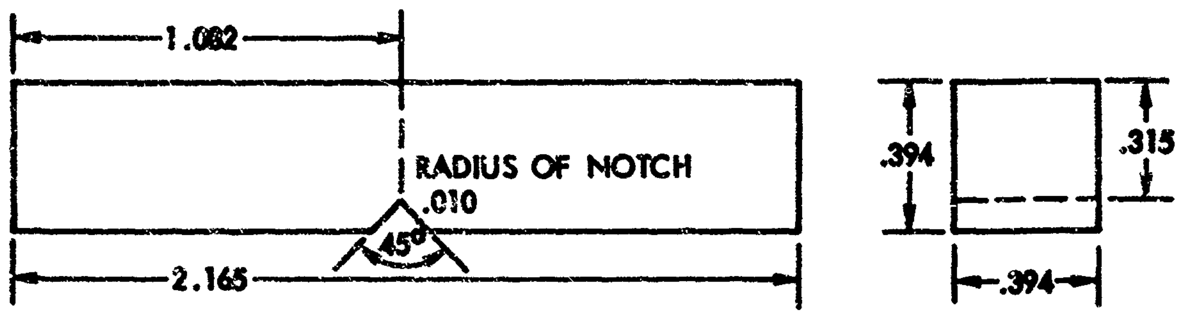


Figure 20. Charpy Specimen, Thick Extrusion

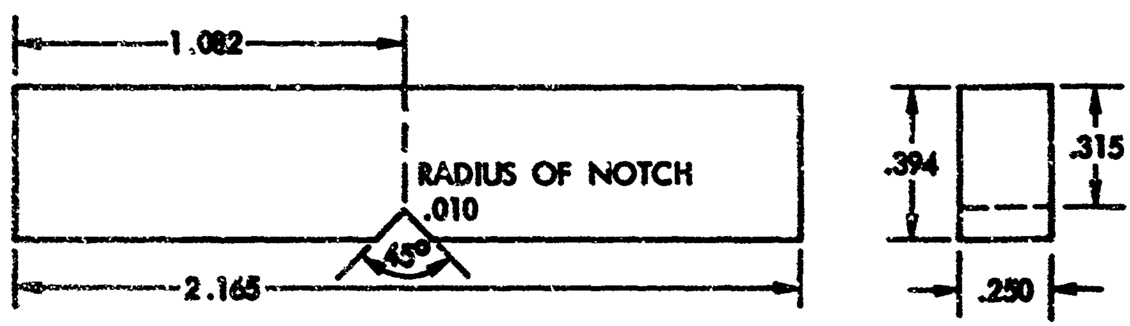


Figure 21. Charpy Specimen, Thin Extrusion

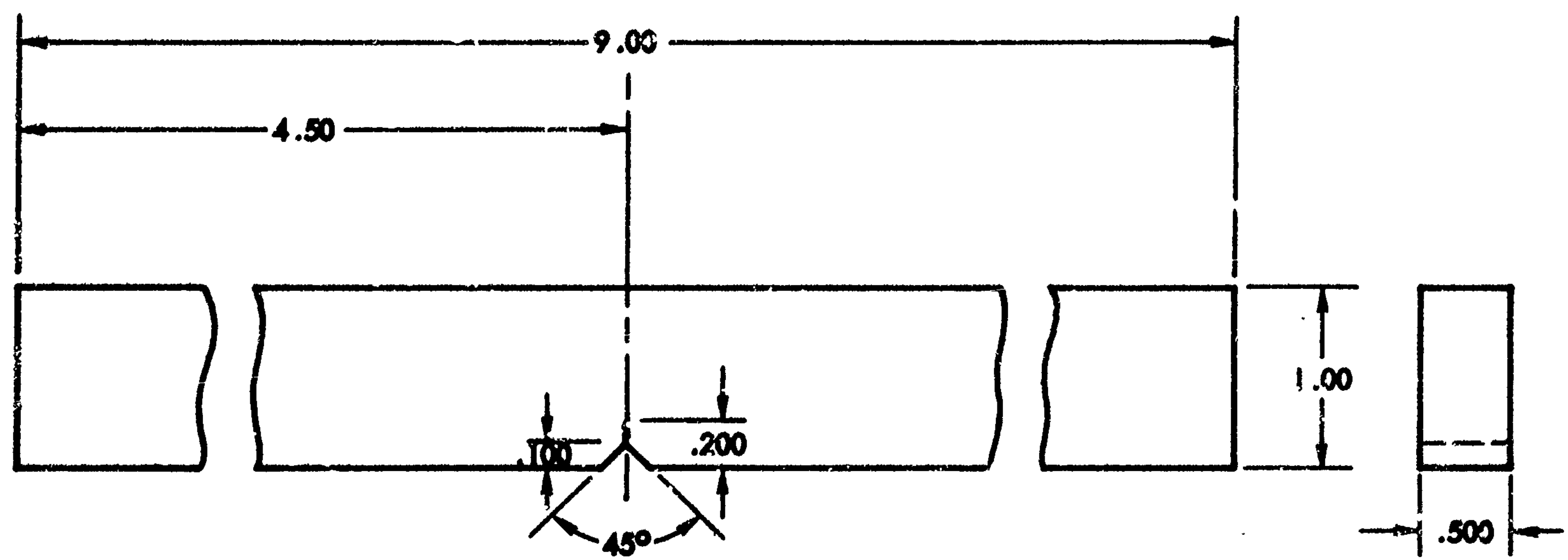


Figure 22. Fatigue Cracked Bend Specimen, Thick Extrusion

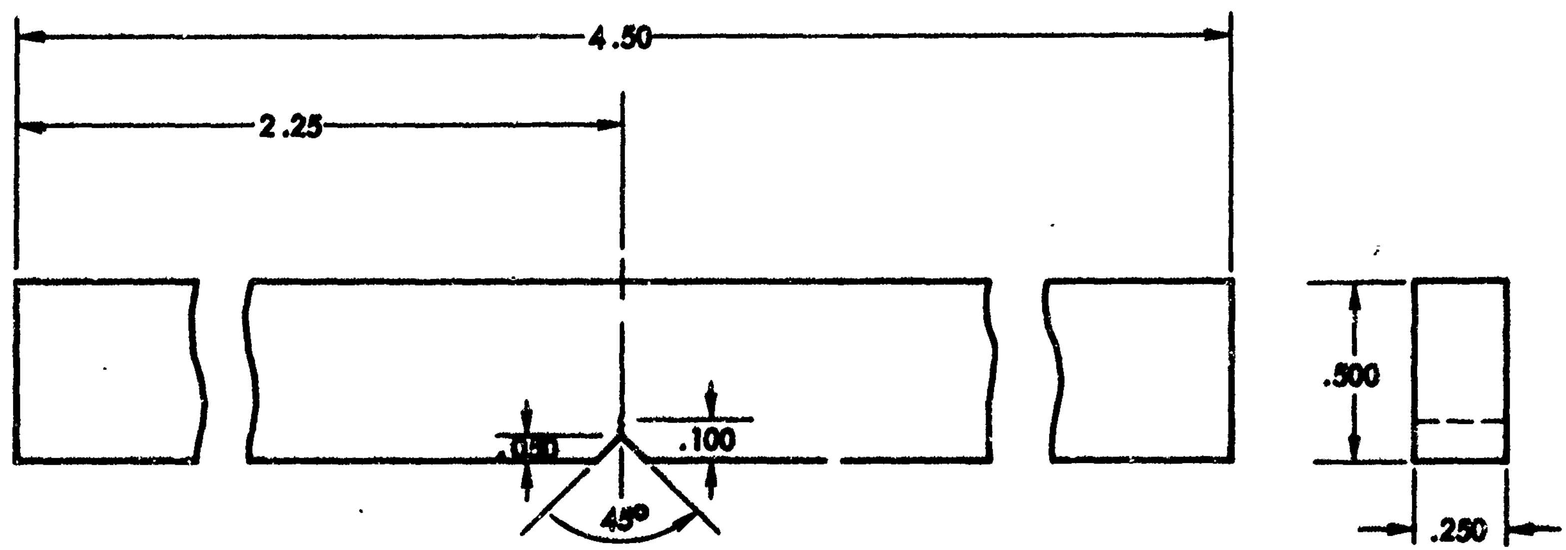


Figure 23. Fatigue Cracked Bend Specimen, Thin Extrusion

B = Specimen thickness (Inches)

W = Specimen width (Inches)

a = Crack depth in the center of the specimen thickness (Inches) (notch plus fatigue crack)

μ = Poisson's ratio = 0.3

The $-110^{\circ}F$ fracture toughness tests were conducted in a CO_2 gas chamber. The specimens were held at the test temperature for 30 minutes before testing. Both the test chamber and the specimen were monitored by thermocouples, and the test temperature of the specimen was maintained at $-110 \pm 5^{\circ}F$. The area of the crack was covered with plastic tape to prevent contamination by moisture.

DELAYED FAILURE TESTS

The delayed failure tests were conducted on the pre-cracked fracture toughness specimens previously described. A transparent plastic strip was taped to each side of the specimen in the area of the crack. A sodium chloride solution (3 1/2 percent by weight sodium chloride in distilled water) was added to the container prior to load application so that the entire crack was covered. The top of the container was left open to the air; if evaporation occurred the container was refilled with distilled water. The level of the solution was kept nearly constant throughout the tests.

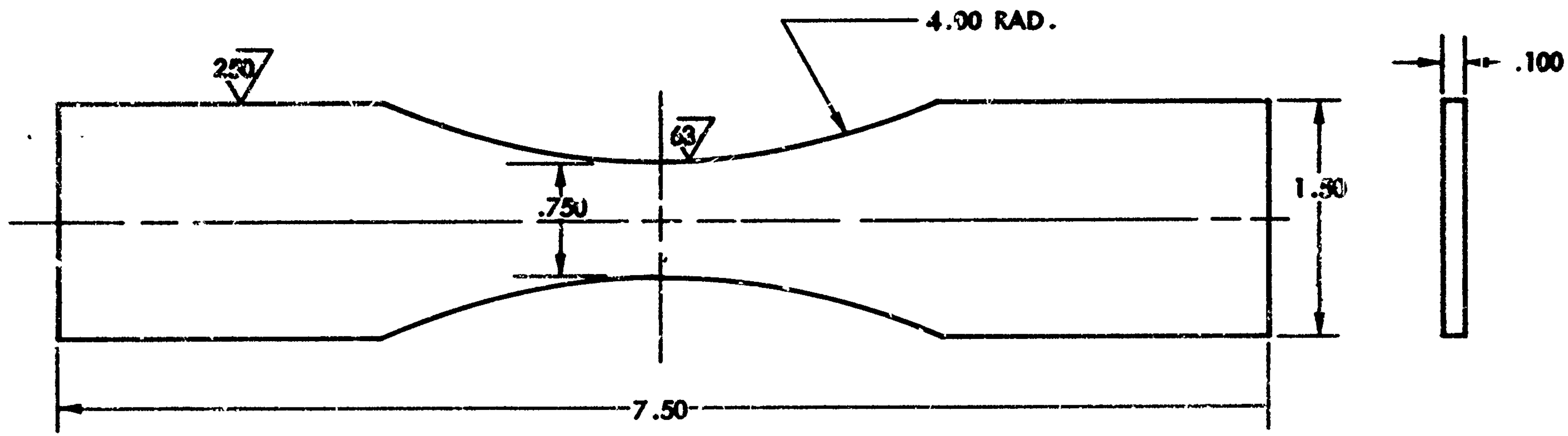
The specimens were stressed at a rate equivalent to a strain rate of 0.005 in/in/min to a predetermined sustained load level which was fifty percent of the ultimate load for the fracture toughness specimens from the same test group. The 1/2-inch wide specimens were tested in a Research Incorporated 100 Kip test machine; the 1-inch wide specimens were tested in Lockheed-designed hydraulic test machines. If a test specimen did not fail during a specified time at the sustained load level, it was loaded to failure. Additional specimens from the same test group were loaded to higher (or lower) load levels until a threshold level at which failure did not occur was determined.

The sustained load level for each specimen is substituted for "P" in the equation for "K_{Ic}" to obtain the sustained load plane-strain stress intensity value which is designated as K_{Ii} and which also has units of Ksi $\sqrt{in.}$

At least one specimen from each test group was held at the threshold level for 100 hours. It should be pointed out that because of the scatter in the test results, the threshold level is defined as the highest K_{Ii} level at which a specimen held, and below which no specimen from the test group failed. There are usually specimens in any test group which do not fail at levels above the threshold K_{Ii} value, but additional specimens from the same group will fail at the same level. The range of the scatter in the K_{Ii} values for titanium alloy specimens is often as much as 10 Ksi $\sqrt{in.}$ units.

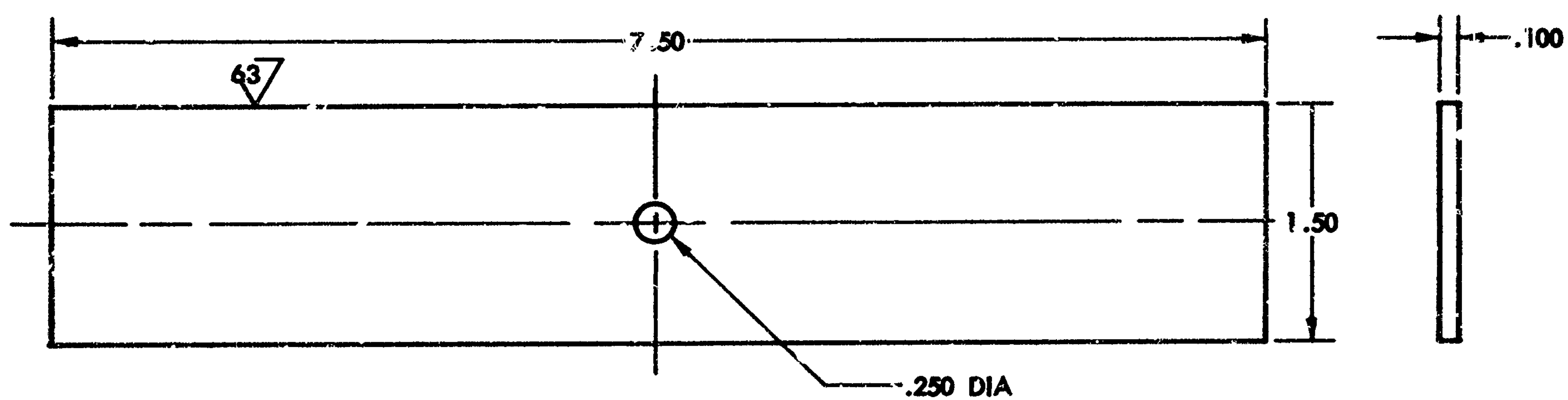
S-N FATIGUE TESTS

The smooth ($K_t = 1$) and center notched ($K_t = 2.7$) fatigue specimens that were used are shown in Figures 24 and 25. The tests were conducted in Lockheed



$K_T = 1.0$

Figure 24. Smooth Fatigue Specimen



$K_T = 2.7$

Figure 25. Notched Fatigue Specimen

designed constant amplitude fatigue test machines at stress ratios (A) of ∞, 0.98 and 0.4. The specimens were tested until failure occurred or until 10^7 cycles had elapsed.

Elevated temperature fatigue tests were conducted in radiant heat furnaces. The specimen test temperature was monitored by a thermocouple and was maintained at the desired level $\pm$ 5°F. The specimens were held at the desired level for 10 minutes before testing. Tests were conducted at 1800 cycles per minute.

Section IV

DISCUSSION OF RESULTS

BASIS FOR EVALUATION

It is considered that this program has developed either two or three data points to be used in conjunction with material from other sources to establish MIL-HDBK-5 values for titanium extrusions (the number of data points depends on the mixture of tests and material source).

Reliability and uniformity of properties within the individual piece were established by room temperature testing. Having obtained this verification, vendor data can be used with confidence to establish room temperature specifications or A and B design values for longitudinal tensile properties. Transverse property data and compressive property data are available in depth from extrusion producers so that statistical values may be obtained by direct methods, or by indirect methods with a broad statistical base.

Effect of temperature on properties, and properties for which design values are normally obtained by derivation have been analyzed to determine that material performance was consistent between vendor, heat, and size. These relationships, in turn, were reviewed in relation to published data on other product forms to establish if the limited information appeared to be part of the same statistical data population, or if significant differences appeared.

UNIFORMITY OF PROPERTIES

Properties throughout all pieces in each of the three alloys tested were considered to be uniform, well within the variations normally expected from extruded material. In the combination of length, test direction, and cross section location within one piece the indicated variation in Ti-6Al-4V tensile ultimate strength (TUS) was under 4%, and variation in TYS less than 5%. In alloys Ti-6Al-6V-2Sn and Ti-8Al-1Mo-1V, the variation within any one piece was under 6% in TUS and under 8% in TYS. Variation in properties between pieces, with location in cross section grain direction, and length is shown in Tables III, IV, and V, and in Figures 26, 27, and 28.

No effect of extrusion direction is apparent from these and other tests. Section location has a random effect, and does not appear to follow a pattern on annealed material. Processing controls to avoid possible degradation of properties because of work effects would allow design in the transverse direction to parallel design in the longitudinal direction. The same principle could also apply in control tests.

TABLE III Ti6Al-4V EXTRUSIONS, VARIATION IN PROPERTIES WITH CROSS SECTION LOCATION, POSITION IN LENGTH, AND PIECE

Piece	Cross Section	Ultimate Tensile Strength (Ksi)			Tensile Yield Strength (0.2%) Ksi			Elongation %			Compressive Yield Strength (0.2%) Ksi		
No.	Location	Front	Center	Rear	Front	Center	Rear	Front	Center	Rear	Front	Center	Rear
A (Thin)	Cap - L	142	144	145	125	127	130	13	16	14	NT	139	139
	Junction - L	141	142	NT	125	126	NT	17	15	NT	137	139	138
	Cap - L	142		141	126		128	14		12	139		
	Stem - L	141	141	142	128	124	128	15	15	14	137	137	137
	Cap - T	142	143	142	127	127	127	14	12	14	139	140	138
B (Thin)	Cap - L	140			125			14					
	Junction - L	140			123			12					
	Cap - L	143			126			17					
	Stem - L	141			124			16					
	Cap - T	143		142	127		126	14		14			
C (Thin)	Cap - L	147	145	143	130	135	128	14	13	14	142	142	NT
	Junction - L	143	144	146	125	128	129	16	15	14	140	142	140
	Cap - L	146		146	129		131	15		15	142		
	Stem - L	143	144	144	127	128	130	18	16	16	142	142	141
	Cap - T	146	146	146	130	130	129	14	15	14	145	144	144
D (Thin)	Cap - L	146			132			16					
	Junction - L	143			127			16					
	Cap - L	145			130			16					
	Stem - L	149			136			14					
	Cap - T	146		147	130		130	14		15			
E (Heavy)	Cap - L	143		144	129		130	14		14			
	Junction - L	140		141	125		127	14		14			
	Stem - L	141		142	126		128	14		14			
	Cap - T	143		144	132		130	14		14			

TABLE IV Ti8Al-1Mo-1V EXTRUSIONS, VARIATION IN PROPERTIES WITH CROSS SECTION, POSITION IN LENGTH, AND PIECE

Piece	Cross Section	Ultimate Tensile Strength (Ksi)			Tensile Yield Strength (0.2%) Ksi			Elongation %			Compressive Yield Strength (0.2%) Ksi		
No.	Location	Front	Center	Rear	Front	Center	Rear	Front	Center	Rear	Front	Center	Rear
F (Thin) 1	Cap - L	138	141	144	125	125	129	13	15	15	137	137	140
	Junction - L	135	135	134	121	121	121	16	18	18	135	135	131
	Cap - L	141		141	126		126	13		15	139		
	Stem - L	138	137	141	123	121	127	14	15	15	134	136	138
	Cap - T	138	137	137	124	122	121	14	15	15	139	138	139
G (Thin)	Cap - L	134			118			21					
	Junction - L	144			127			16					
	Cap - L	143			124			19					
	Stem - L	139			122			19					
	Cap - T	137		138	120		121	17		15			
H (Thin)	Cap - L	134	134	134	118	119	120	15	17	16	132	128	130
	Junction - L	129	131	131	114	116	116	18	16	17	129	131	128
	Cap - L	136		137	122		124	18		16	153		
	Stem - L	134	134	132	121	120	118	17	16	16	131	132	132
	Cap - T	133	132	132	118	117	117	[illegible]	17	15	135	132	133
J (Thin)	Cap - L	136			122			18					
	Junction - L	133			119			16					
	Cap - L	134			119			13					
	Stem - L	135			121			18					
	Cap - T	135		133	120		117	15		16			
K (Heavy)	Cap - L	138		138	126		126	12		15			
	Junction - L	132		133	119		121	14		15			
	Stem - L	134		132	122		120	15		15			
	Cap - T	136		137	123		125	14		15			

TABLE V Ti6Al-6V-2Sn EXTRUSIONS, VARIATION IN PROPERTIES WITH CROSS SECTION LOCATION, POSITION IN LENGTH, AND PIECE

Piece	Cross Section	Ultimate Tensile Strength (Ksi)			Tensile Yield Strength (0.2%) Ksi			Elongation %			Compressive Yield Strength (0.2%) Ksi		
No.	Location	Front	Center	Rear	Front	Center	Rear	Front	Center	Rear	Front	Center	Rear
L (Thin)	Cap - L	157	158	159	140	139	142	15	15	13	154	156	156
	Junction - L	154	157	158	138	132	140	14	14	14	154	152	155
	Cap - L	157		159	140		143	15		13	154		
	Stem - L	164	156	158	144	NT	141	15	15	14	153	154	156
	Cap - T	155	160	159	140	142	144	12	14	13	159	157	159
M (Thin)	Cap - L	160			140			16					
	Junction - L	158			138			16					
	Cap - L	154			136			15					
	Stem - L	157			137			17					
	Cap - T	159		160	140		143	15		14			
K (Thin)	Cap - L	153	146	148	136	132	134	15	15	15	147	143	149
	Junction - L	147	143	145	134	131	132	16	17	17	148	147	146
	Cap - L	147		150	133		135	18		16	150		
	Stem - L	150	146	145	135	133	132	17	18	17	148	149	148
	Cap - T	152	151	150	137	135	135	16	16	15	153	151	149
P (Thin)	Cap - L	145			134			20					
	Junction - L	142			131			21					
	Cap - L	146			135			18					
	Stem - L	147			136			19					
	Cap - T	148		150	134		135	18		17			
R (Heavy)	Cap - L	157		156	142		140	12		13			
	Junction - L	156		154	136		136	13		15			
	Stem - L	154		154	137		137	15		14			
	Cap - T	161		161	145		147	13		12			

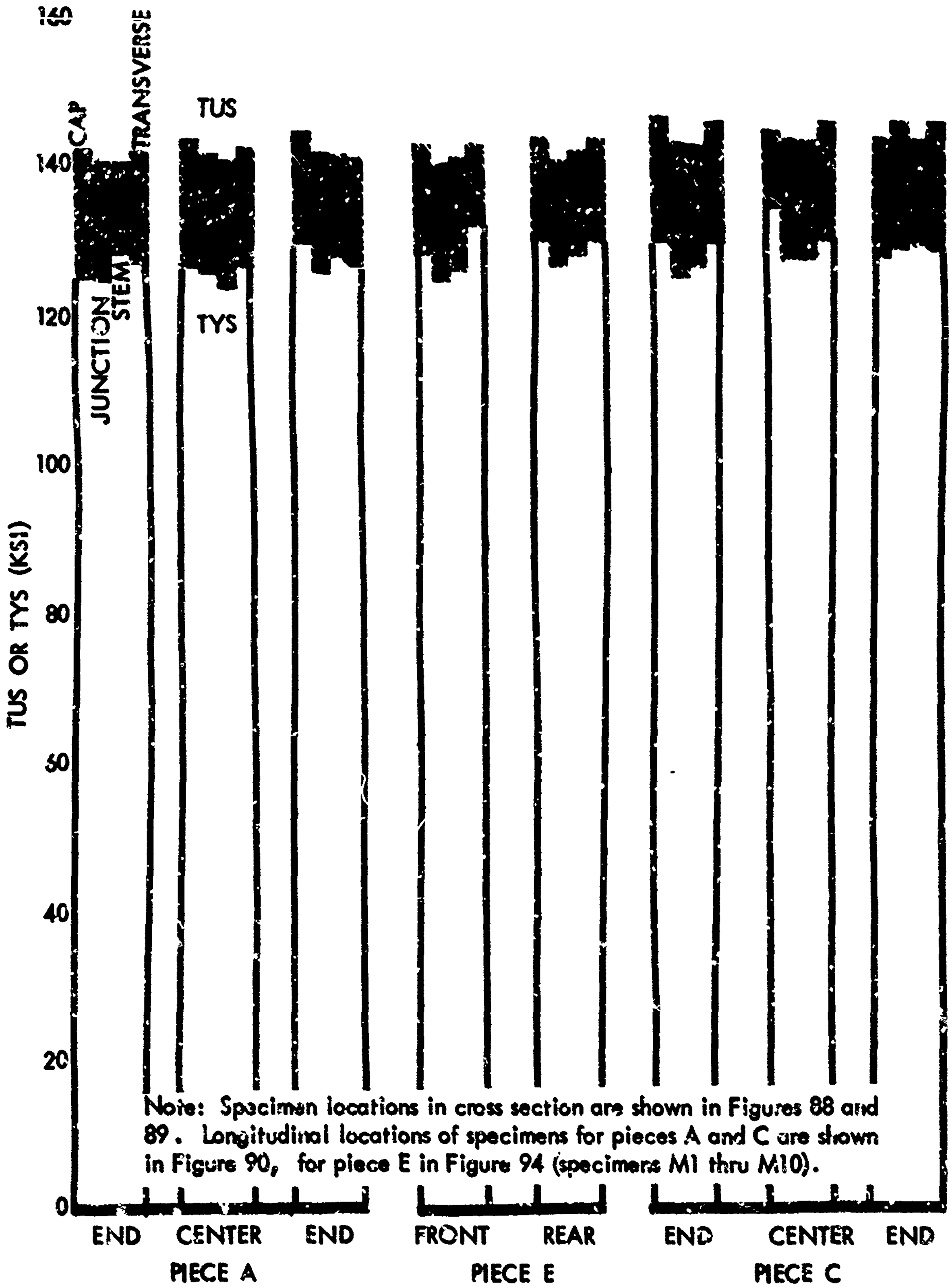


Figure 26. Comparison of Variation in TUS and TYS with Location in Cross Section in Length and Between Vendors, Sections, and Heat Ti-6Al-4V Extrusions

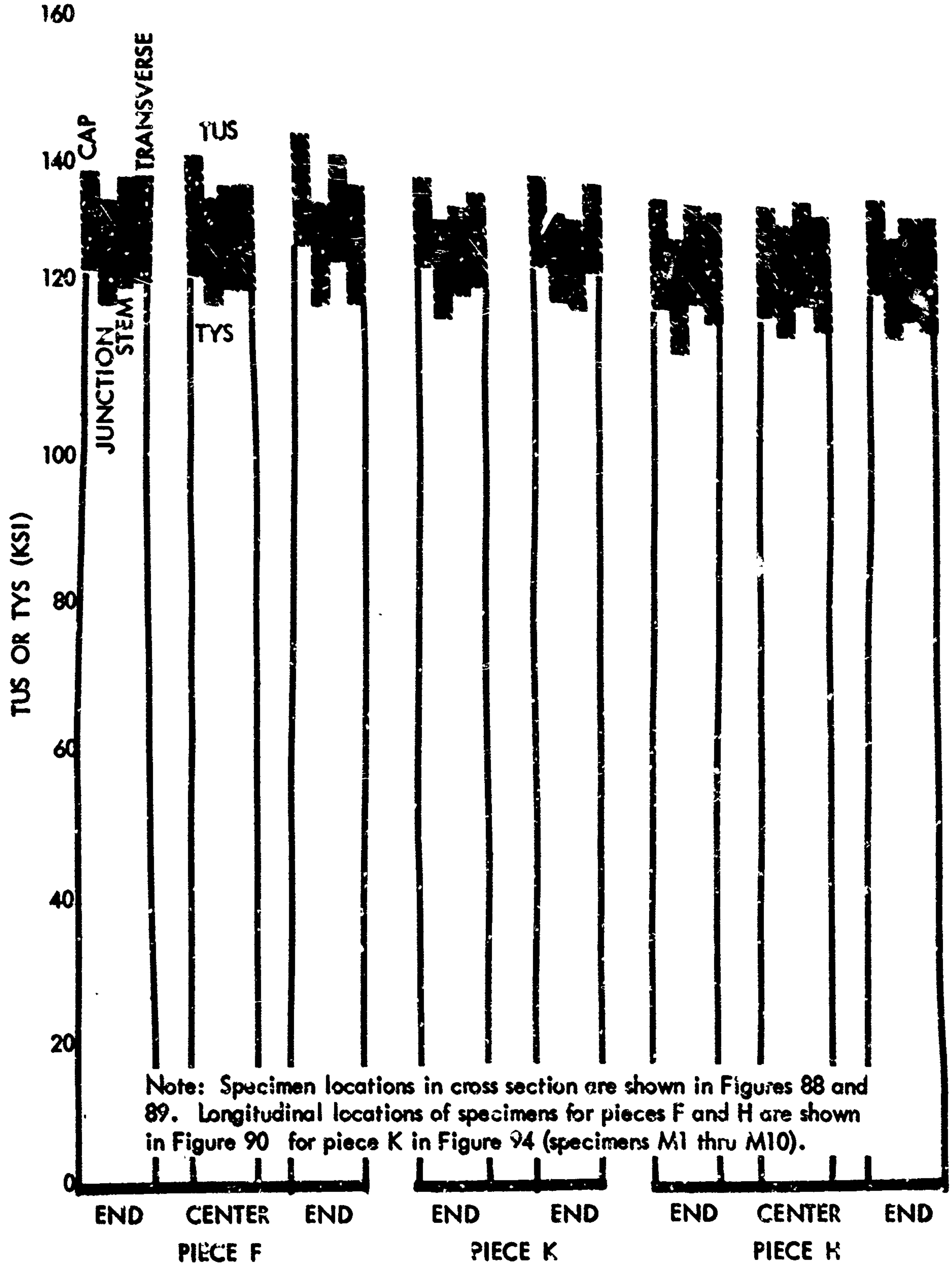


Figure 27. Comparison of Variation in TUS and TYS with Location in Cross Section, in Length and Between Vendors, Section and Heat Ti-8Al-1Mo-1V Extrusions

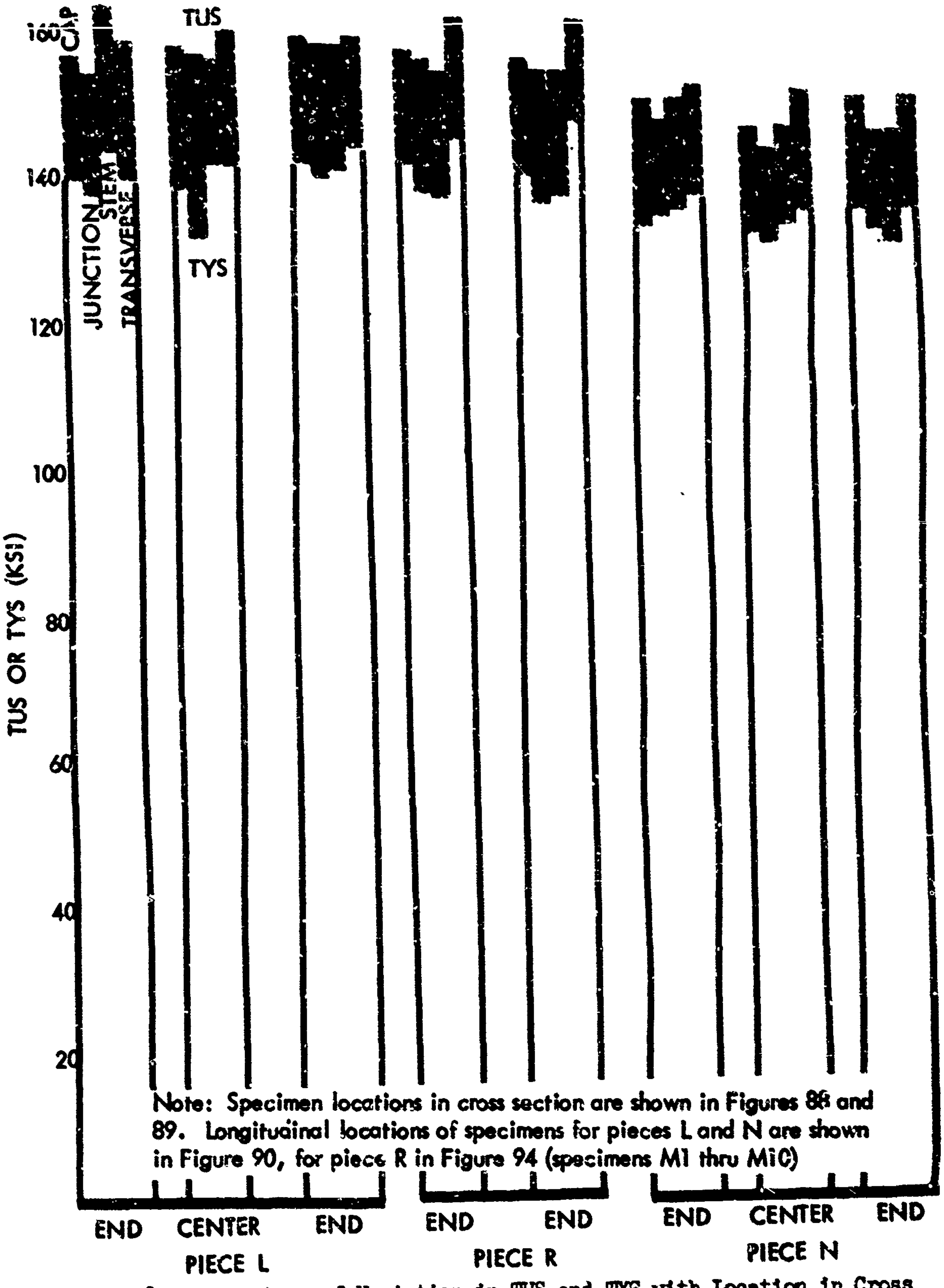


Figure 28. Comparison of Variation in TUS and TYS with Location in Cross Section, in Length, and Between Vendors, Sections and Heat Ti-6Al-6V-2Sn Extrusions

RELATIONSHIPS BETWEEN VENDORS

Sufficient data points do not exist within this program to establish relationships between vendors, except as related to a single test point only. The relation - and property scatter - between vendors should be determined from vendor accumulated property data. From the limited points, comments are as follows:

Properties of the Ti-6Al-4V extrusions supplied by the two vendors were, as shown in Figure 26, quite close. Total spread between values was less than 10%. The percentage relation on temperature effects and on derived properties such as shear and bearing appeared consistent. Relation of test data to a normal mill property distribution may be obtained by comparison with Figure 29.

Ti-6Al-6V-2Sn extrusions appeared to show a slightly greater margin of differences between vendors, possibly based on production background in the alloy. Property relationships to room temperature properties were consistent. General relationships are shown in Figure 28. Typical distribution of vendor tests for TUS is shown in Figure 30.

Ti-8Al-1Mo-1V showed greater differences than the other alloys. The discrepancy did not appear at room temperature, but both sub-zero and elevated temperatures tests seemed to indicate a change in temperature effect. Room temperature relationships are shown in Figure 27. Figure 31 shows a typical distribution of TUS test results based on vendor data.

The yield strengths shown for pieces H and J (Ti-8Al-1Mo-1V) and for pieces N and P (Ti-6Al-6V-2Sn) are lower than those shown for the alloys in Section V. The values shown as design minimums are at present consistently being achieved by one vendor as shown by Figures 30 and 31, and are presently being used in design.

MODULUS OF ELASTICITY

Precision modulus determination showed typical tensile modulus of elasticity at room temperature values as follows:

Ti-8Al-1Mo-1V	17.6×10^6 psi
Ti-6Al-4V	16.9×10^6 psi
Ti-6Al-6V-2Sn	16.1×10^6 psi

Values for the Ti-8Al-1Mo-1V agree with MIL-HDBK-5 values for other product forms of this alloy, the other two alloys have indicated modulus values higher than those shown for other product forms in MIL-HDBK-5. The relationship between alloys is in accordance with the expected pattern.

TEMPERATURE EFFECTS ON TENSILE AND COMPRESSIVE PROPERTIES

The effect of temperature on tensile properties of the three alloys is shown in Figures 5 and 6, and effect on compression yield strength in Figure 7. Temperature effect data has been plotted to show effect as percent of the room temperature property value and is presented in Section V.

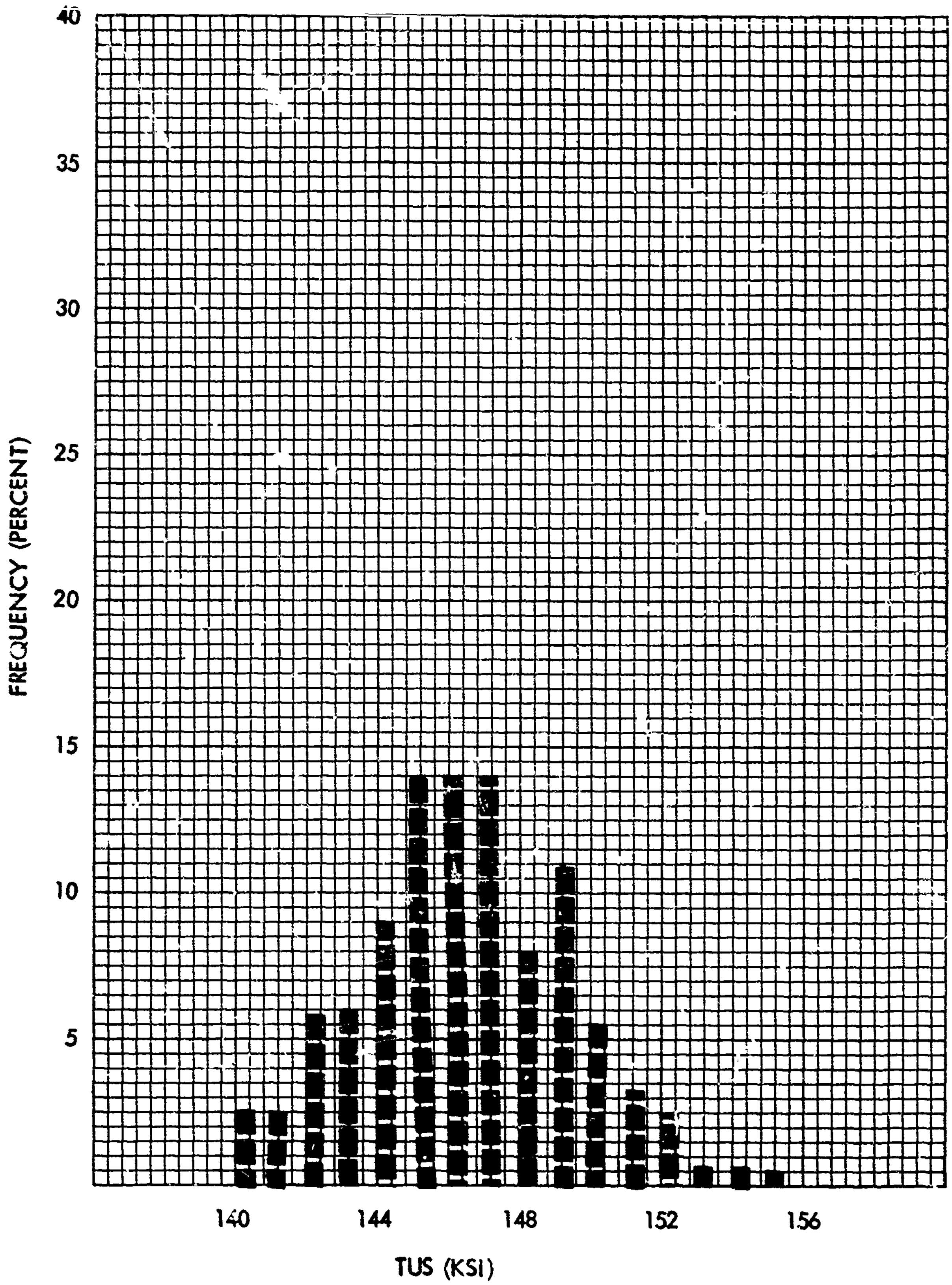


Figure 29. Typical Distribution of Test Results Annealed Ti-6Al-4V Extrusions (170 Tests)

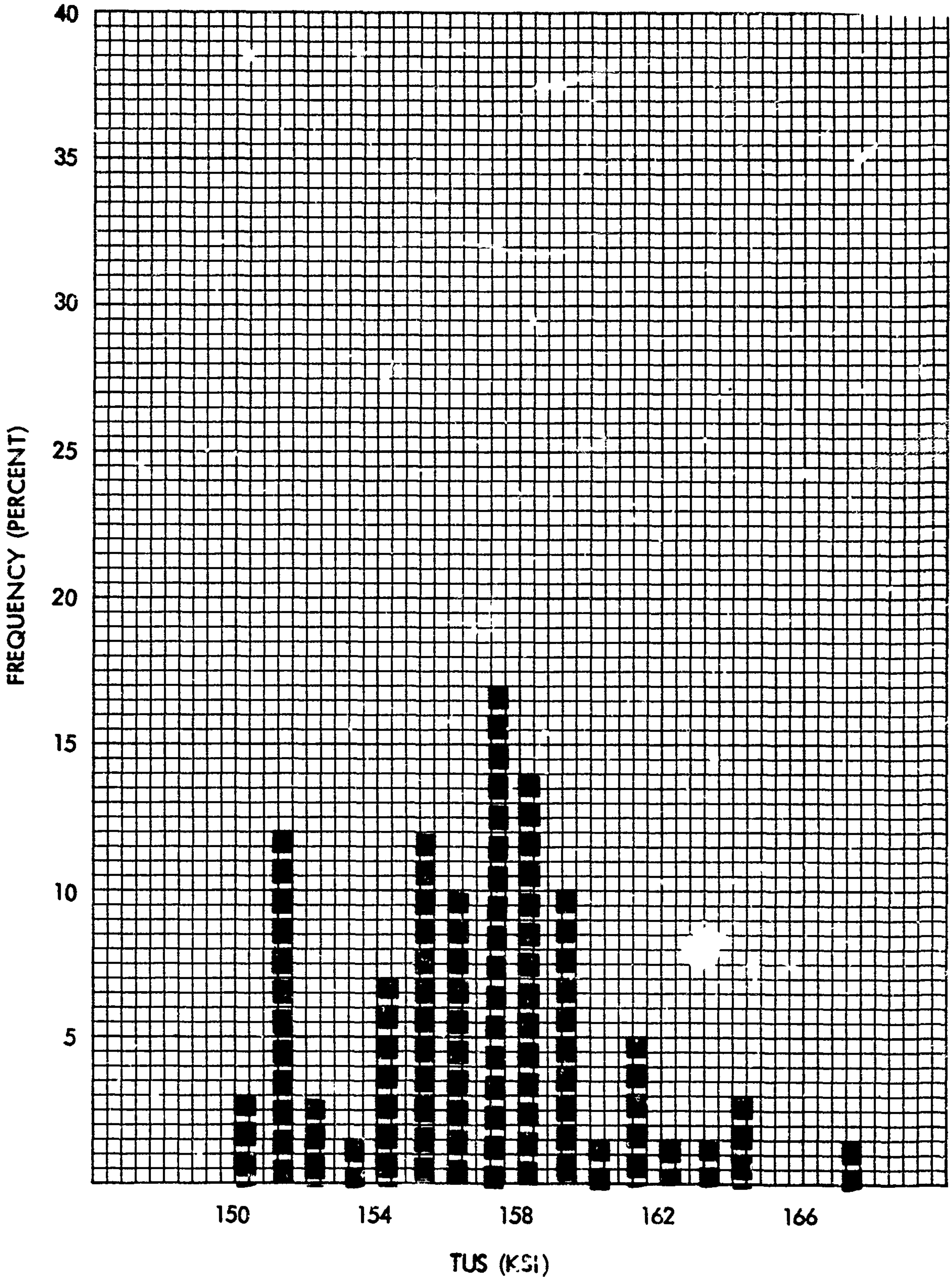


Figure 30. Typical Distribution of Test Results Annealed Ti-6Al-6V-2Sn Extrusions (60 Tests)

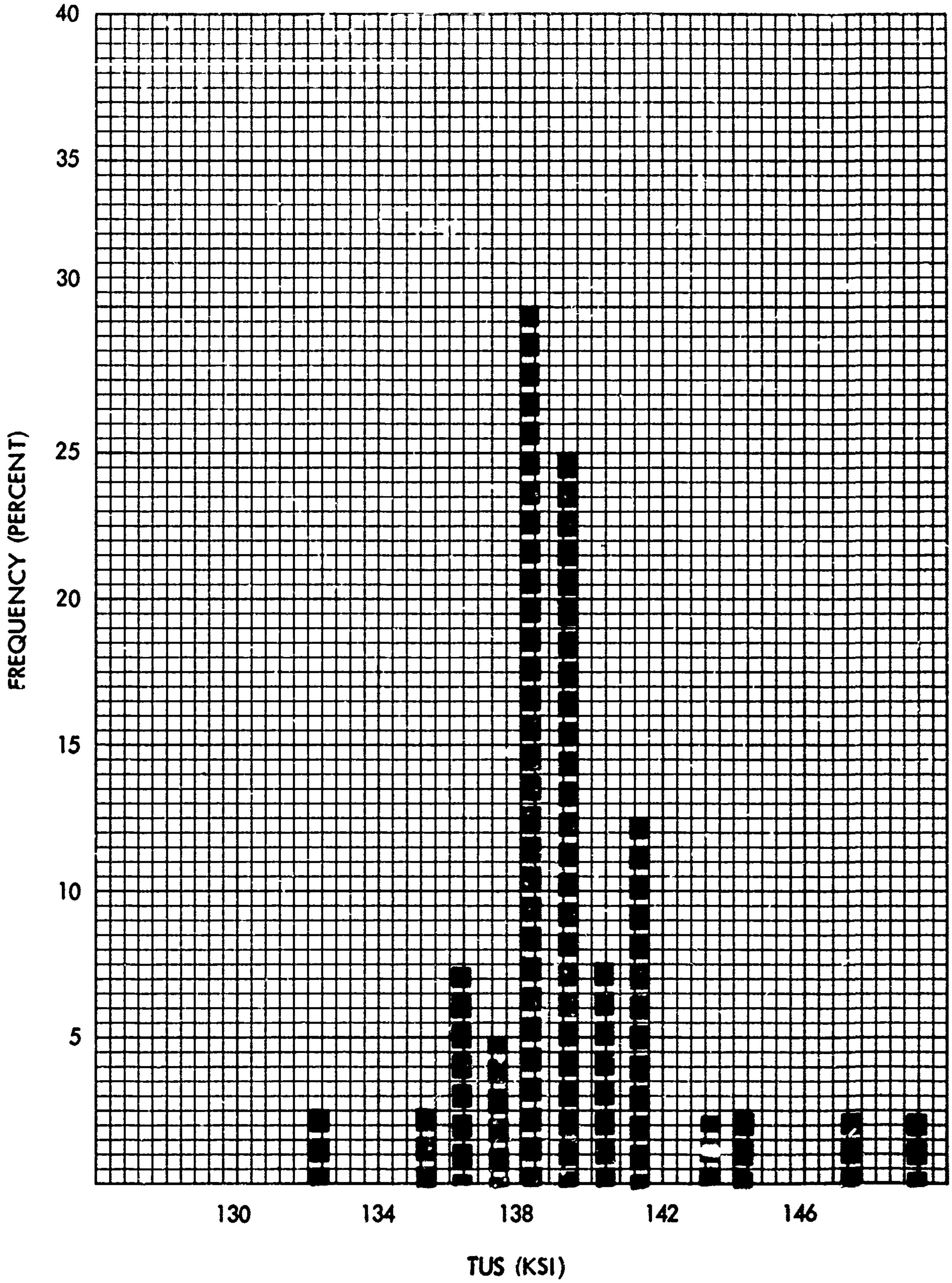


Figure 31. Typical Distribution of Test Results Annealed Ti-8Al-1Mo-LV Extrusions (40 Tests)

Two comparison points at each temperature (one from each vendor) were established in the longitudinal direction and one data point at each temperature in the transverse direction. Temperature effect relationships were consistent between vendors and grain directions. Tables VI, VII, and VIII indicate these trends.

Sufficient data points have not been established by this program to provide verification of the depth required for MIL-HDBK-5. The pattern thus far however is consistent and appears to indicate that the reduction in properties at elevated temperature is in excess of that shown in MIL-HDBK-5 for other product forms of these alloys. Comparison of temperature effects are shown in Figures 32 through 39, inclusive.

In the higher temperatures, effects on Ti-6Al-6V-2Sn appear to be less than on the other alloys. This follows trends in other Lockheed investigations covering other heat treat conditions, and follows patterns shown in MIL-HDBK-5 for other products.

BEARING

Results of tests for ultimate bearing strength and for bearing yield strength are summarized in Tables IX and X. The normal pattern of reduced strength at elevated temperature is followed, with alloys maintaining normal strength relationships. Effect of elevated temperature on the 600°F properties of Ti-6Al-6V-2Sn appears to be less than that of the other alloys - corresponding to the trends shown in properties such as tensile strength.

Agreement of values and of ratios between vendors is considered normal considering the limited number of data points. Ratios of ultimate bearing strength to ultimate strength, and of bearing yield strength to tensile yield strength are of the same general order of magnitude as those given in MIL-HDBK-5 for other product forms. Additional data points are required to define ratio and temperature effects more precisely.

SHEAR

Results of tests to determine ultimate shear strengths are summarized in Table XI.

Values obtained agree closely between vendors and between grain directions. Ratios of bearing strength to ultimate strength closely coincide with published values for other product forms, and temperature effect curves follow patterns established for other products.

Ti-6Al-6V-2Sn again shows less effect on properties from elevated temperature than that shown by the other alloys.

CREEP AND STRESS RUPTURE

Creep and stress rupture testing was initiated in accordance with the contract test schedule. Because of the resistant characteristics of the extruded product form to creep, the program was modified to provide stress rupture data

TABLE VI EFFECT OF TEMPERATURE ON THE ULTIMATE TENSILE STRENGTH OF TITANIUM ALLOY EXTRUSIONS

Alloy	Piece	Test Direction	Percent of Room Temperature Strength				
			-110F	RT	400F	600F	800F
Ti-6Al-4V	A	L	122	100	78	71	65
	C	L	121	100	78	70	66
	A	T	120	100	77	72	66
Ti-8Al-1Mo-1V	F	L	121	100	83	77	71
	H	L	117	100	79	71	66
	F	T	119	100	82	76	69
Ti-6Al-6V-2Sn	L	L	119	100	79	77	69
	N	L	118	100	85	79	74
	L	T	120	100	83	79	72

TABLE VII EFFECT OF TEMPERATURE ON TENSILE YIELD STRENGTH OF TITANIUM ALLOY EXTRUSION

Alloy	Piece	Test Direction	Percent of Room Temperature Strength				
			-110F	RT	400F	600F	800F
Ti-6Al-4V	A	L	128	100	71	61	58
	C	L	125	100	72	59	57
	A	T	127	100	70	62	57
Ti-8Al-1Mo-1V	F	L	130	100	72	65	58
	H	L	120	100	72	58	53
	F	T	126	100	73	65	58
Ti-6Al-6V-2Sn	L	L	127	100	72	69	62
	N	L	121	100	78	69	66
	L	T	127	100	76	69	64

TABLE VIII EFFECT OF TEMPERATURE ON THE COMPRESSIVE YIELD STRENGTH OF TITANIUM ALLOY EXTRUSIONS

Alloy	Piece	Test Direction	Percent of Room Temperature Strength				
			-110F	RT	400F	600F	800F
Ti-6Al-4V	A	L	125	100	67	57	56
	C	L	123	100	70	59	55
	A	T	125	100	69	59	56
Ti-8Al-1Mo-1V	F	L	125	100	72	60	57
	H	L	124	100	70	59	54
	F	T	125	100	71	61	56
Ti-6Al-6V-2Sn	L	L	127	100	74	67	62
	N	L	124	100	74	68	64
	L	T	127	100	74	67	63

only at 400°F, to provide both limited creep and stress-rupture data at 600°F and to provide a limited probe at 800°F creep characteristics. In addition, a probe was made of creep under conditions of rapid heating and loading such as might occur under over ride conditions. General airframe parameters were considered rather than such specialized applications as engines where extensive special creep investigations would be conducted.

400°F CHARACTERISTICS

Tests indicated that creep at 400° should not be considered to be significant in general airframe design. In order to produce 0.1 percent strain in 1000 hours, Ti-6Al-4V and Ti-8Al-1Mo-1V specimens were loaded to approximately 95 percent of the ultimate strength at temperature, a level twenty to thirty percent above yield. The same level of stress produced 0.2 percent combined creep and strain deformation in Ti-6Al-6V-2Sn.

Stress Rupture at 400F is considered to be coincident with the ultimate tensile strength. Tests within a nominal 2 ksi of the ultimate tensile strength at temperature failed on loading or showed no failure at one week exposure. Since stress rupture characteristics were directed toward use in construction of fatigue diagrams the stress rupture curve was considered to coincide with the tensile strength within test limits.

600°F CHARACTERISTICS

Stress-rupture and nominal ultimate tensile strength at temperature were considered to be coincident. Ti-6Al-4V and Ti-6Al-6V-2Sn specimens loaded within 2 ksi of ultimate strength at temperature did not fail in 1000 hours of exposure. Tests of the Ti-8Al-1Mo-1V at the same relative load were discontinued at approximately 650 hours without failure.

Creep in Ti-8Al-1Mo-1V and in Ti-6Al-4V did not appear significant at the 600°F yield stress. Tests of Ti-8Al-1Mo-1V at yield strength indicate less than

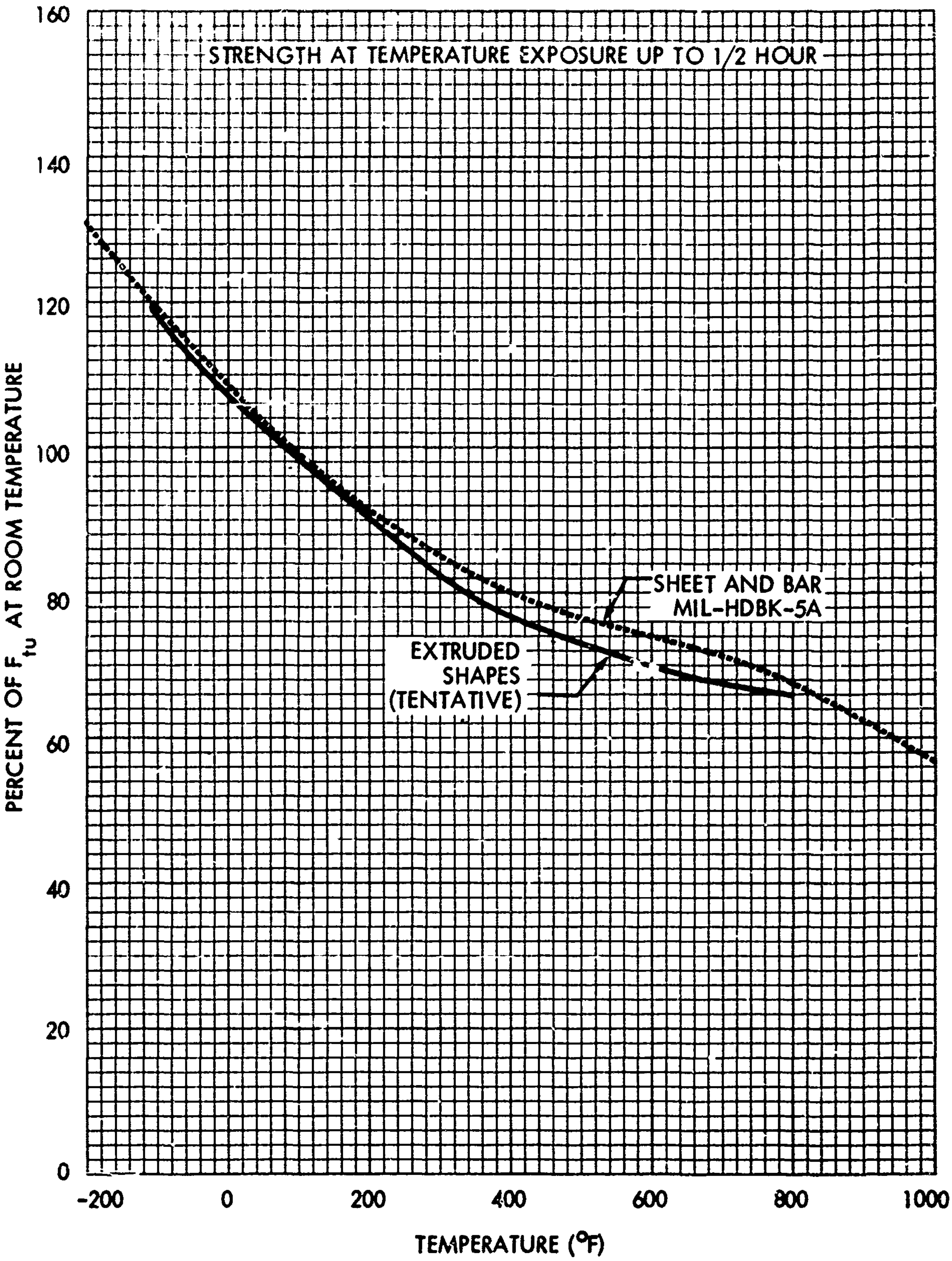


Figure 32. Comparison of Effect of Temperature on Ultimate Tensile Strength (Ftu) of Annealed Ti-6Al-4V Extrusion and Ti-6Al-4V Sheet and Bar

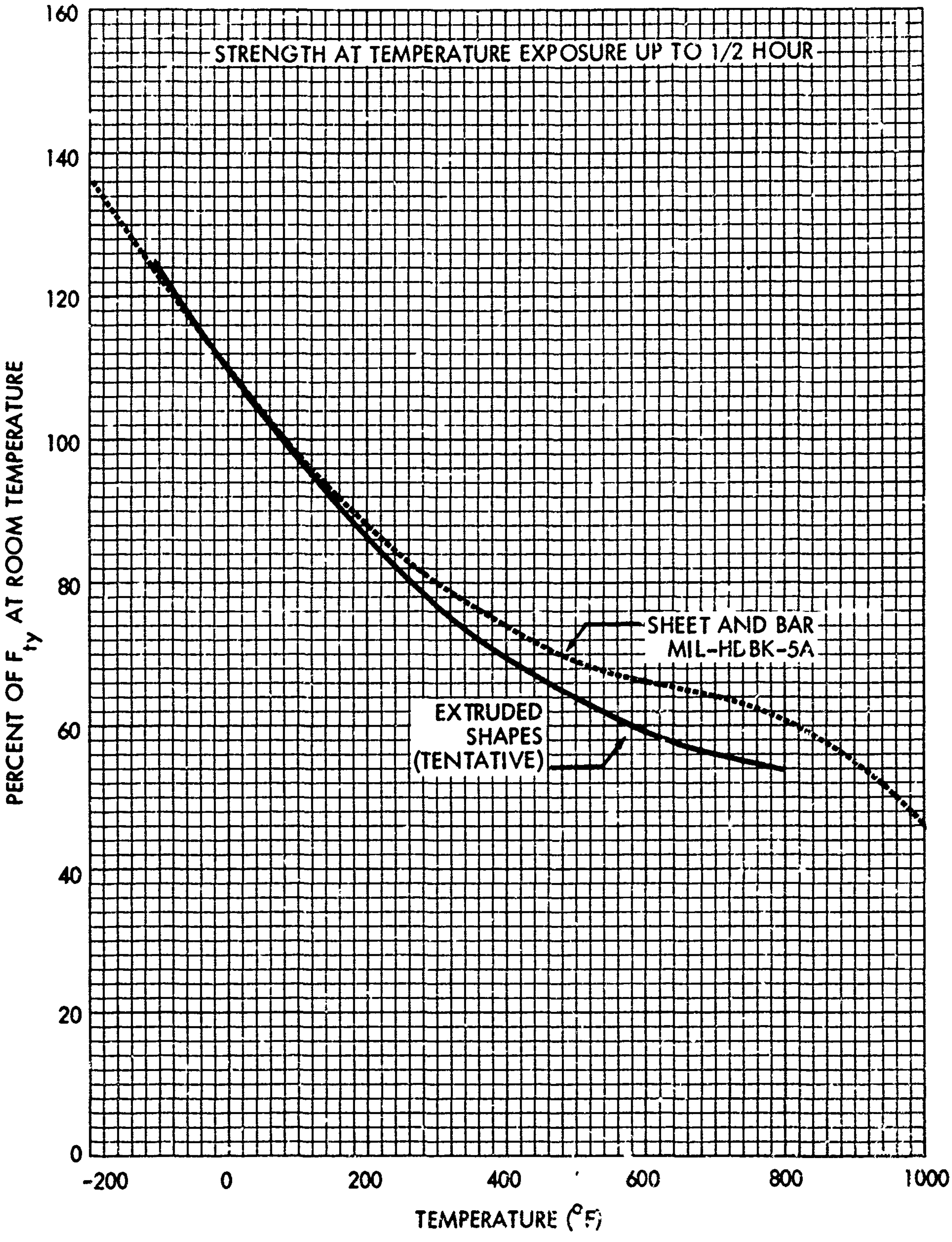


Figure 33. Comparison of the Effect of Temperature on the Tensile Yield Strength (F_{ty}) of Annealed Ti-6Al-4V Extrusion and Ti-6Al-4V Sheet and Bar

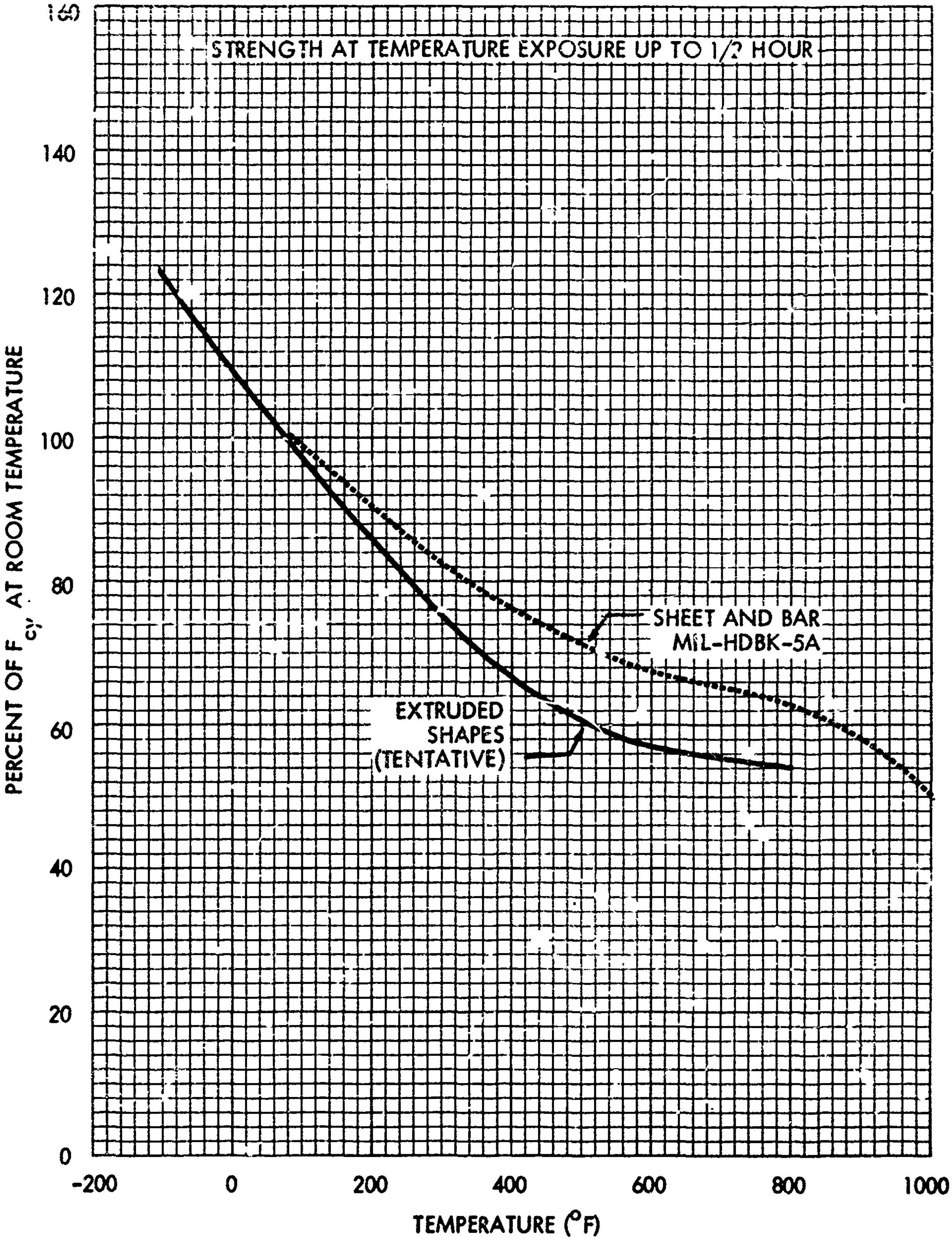


Figure 34. Comparison of the Effect of Temperature on the Compressi Yield Strength (F_{cy}) of Annealed Ti-6Al-4V Extrusion and Ti-6Al-4V Sheet and Bar

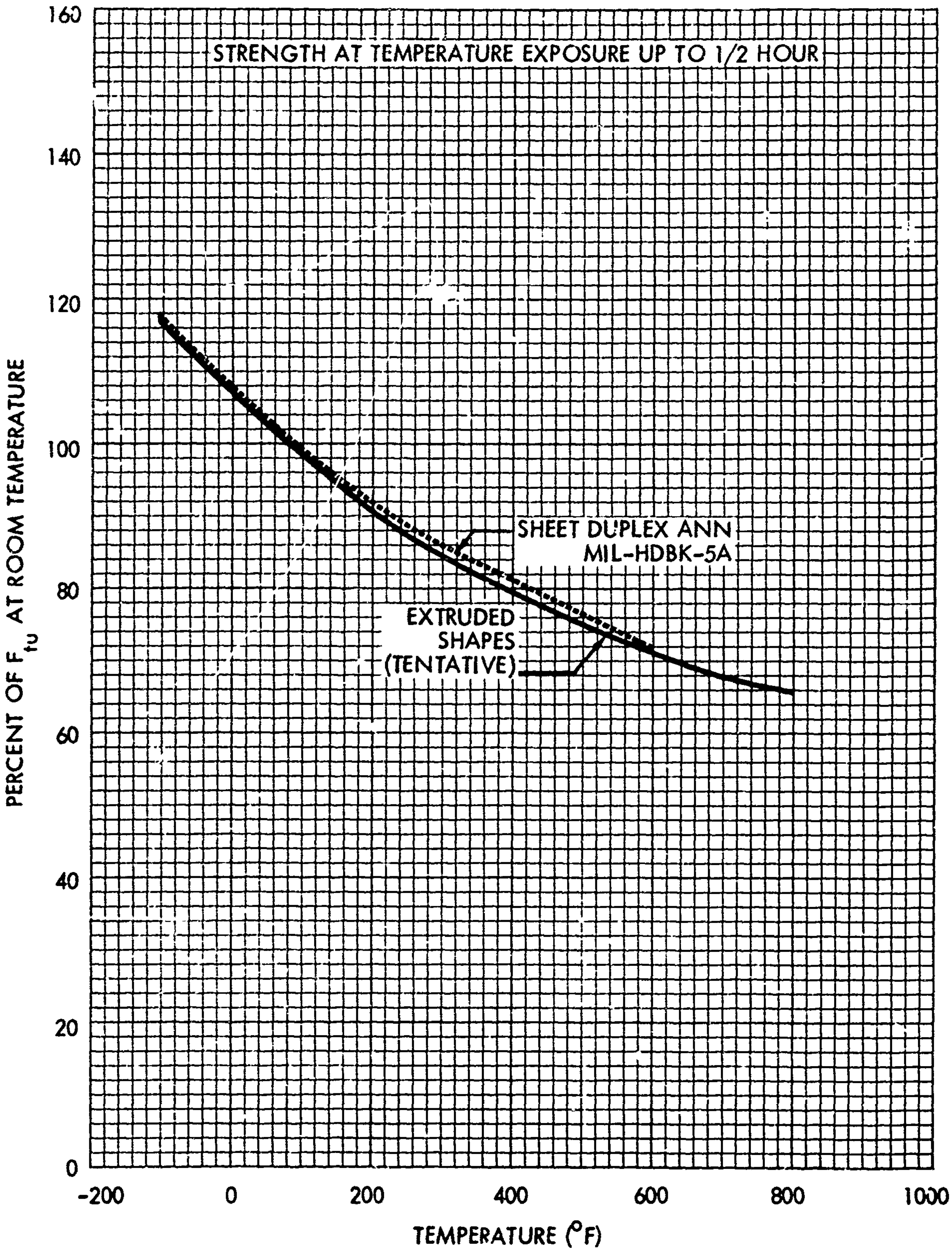


Figure 35. Comparison of the Effect of Temperature on the Ultimate Tensile Strength (F_{tu}) of Annealed Ti-8Al-1Mo-1V Extrusion and Ti-8Al-1Mo-1V Sheet

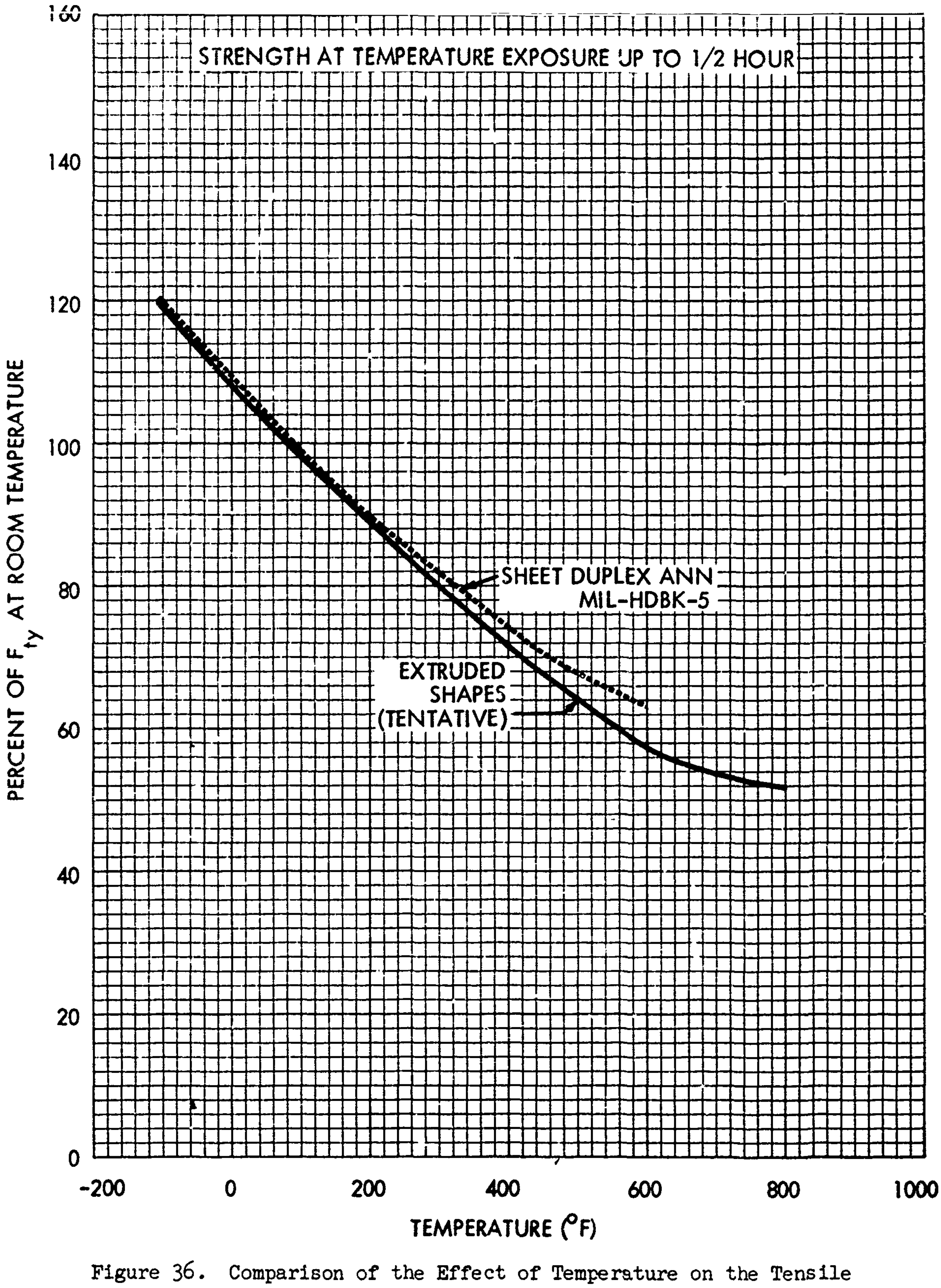


Figure 36. Comparison of the Effect of Temperature on the Tensile Yield Strength of Annealed Ti-8Al-1Mo-1V Extrusion and Ti-8Al-1Mo-1V Sheet

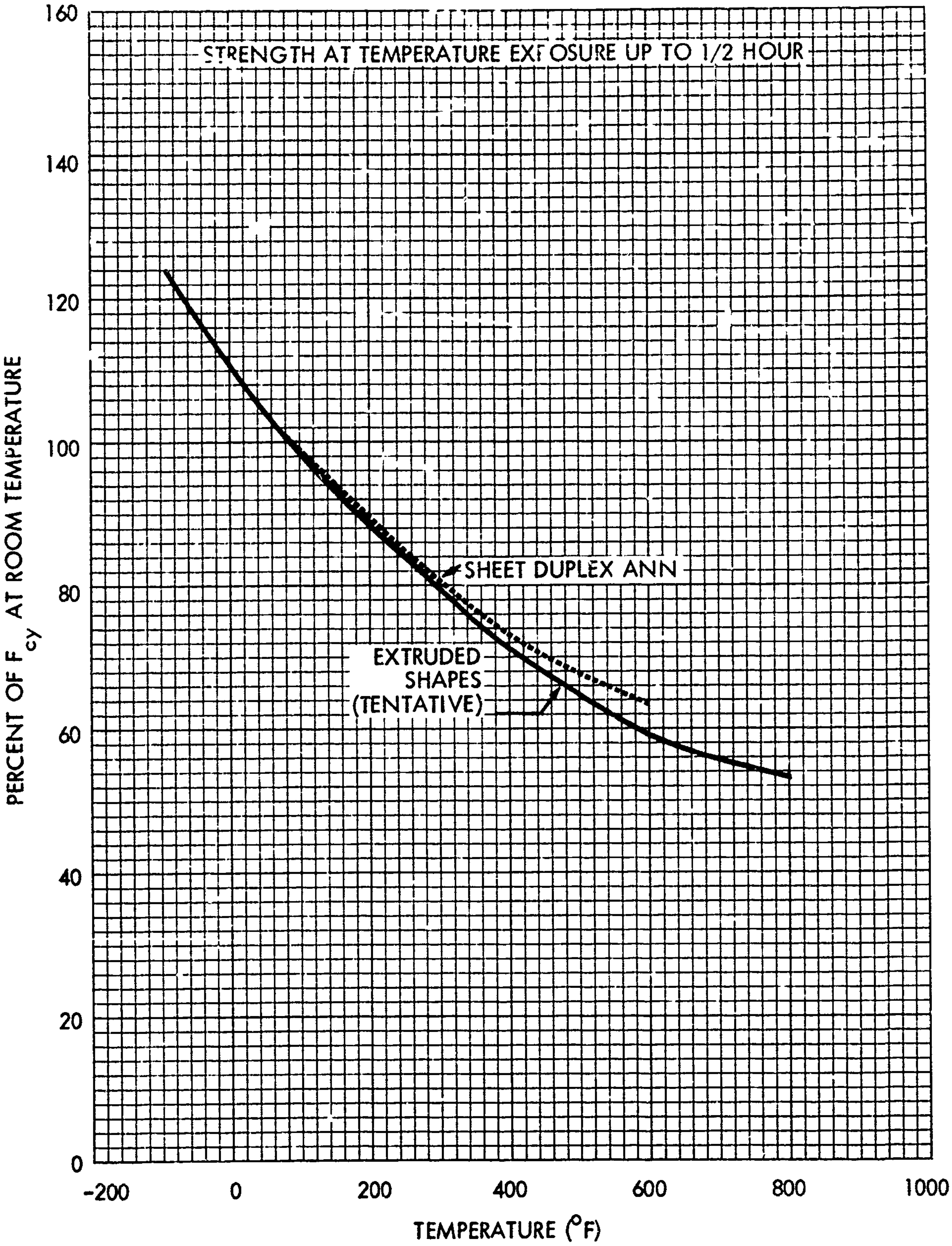


Figure 37. Comparison of the Effect of Temperature on the Compressive Yield Strength (F_{cy}) of Annealed Ti-8Al-1Mo-1V Extrusion and Ti-8Al-1Mo-1V Sheet

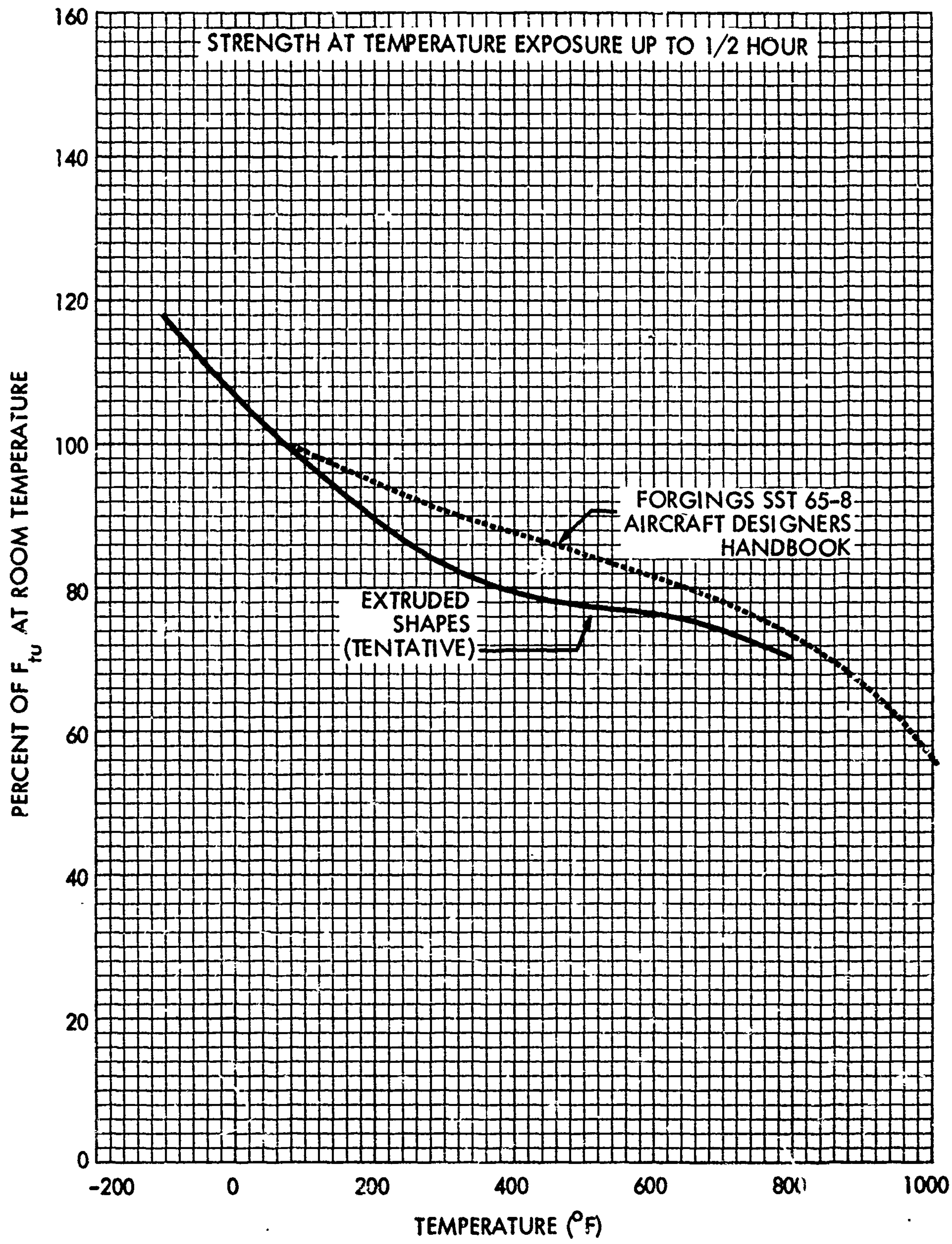


Figure 38. Comparison of the Effect of Temperature on the Ultimate Tensile Strength (F_{tu}) of Annealed Ti-6Al-6V-2Sn Extrusions and Ti-6Al-6V-2Sn Forgings

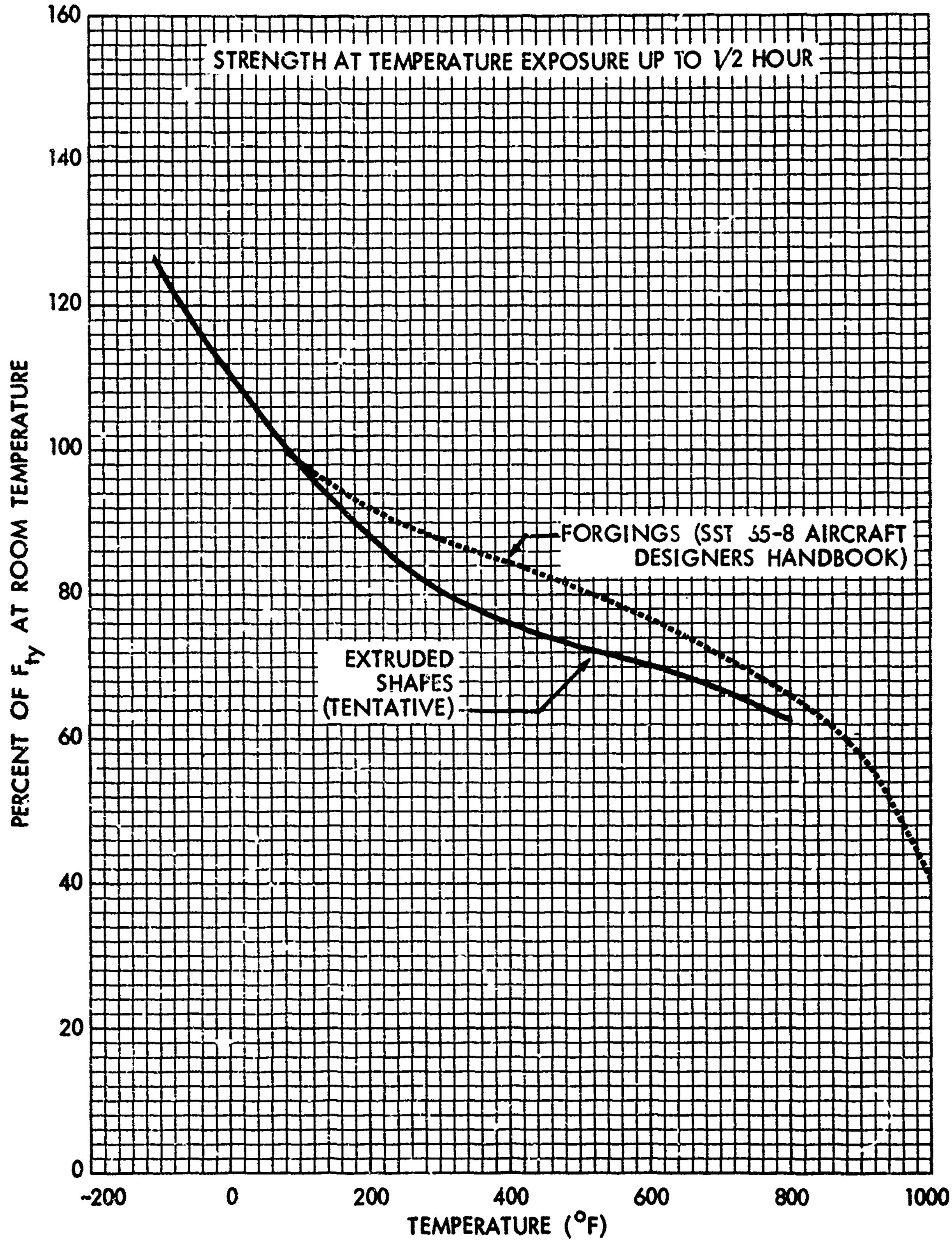


Figure 39. Comparison of Effect of Temperature on the Tensile Yield Strength (F_{ty}) of Annealed Ti-6Al-6V-2Sn Extrusions and Ti-6Al-6V-2Sn Forgings

TABLE IX ULTIMATE BEARING STRENGTHS OF TITANIUM EXTRUSIONS (1)

Description				Ultimate Bearing Strength at Temperature, Ksi				Percent of TUS at RT
Alloy	Piece	Direction	e/D	-110F	RT	400F	600F	
Ti-6Al-4V	A	L	2.0	330	295	210	201	208
	C	L	2.0		276	228	204	189
	A	T	2.0		301	225		212
	C	T	2.0		296			203
	A	L	1.5		244			172
	C	L	1.5		247			169
Ti-8Al-1Mo-1V	F	L	2.0	323	292	220	192	210
	H	L	2.0		270	215	191	200
	F	T	2.0		291	222		211
	H	T	2.0		323			243
	F	L	1.5		239			172
	H	L	1.5		222			164
Ti-6Al-6V-2Sn	L	L	2.0	357	316	255	216	201
	N	L	2.0		297	250	236	198
	L	T	2.0		341	248		214
	N	T	2.0		317			208
	L	L	1.5		269			171
	N	L	1.5		252			168

(1) Average of three tests

TABLE X BEARING YIELD STRENGTHS OF TITANIUM EXTRUSIONS [1]

Description				Bearing Yield Strength at Temperature, Ksi				Percent of TYS at RT
Alloy	Piece	Direction	e/D	-110F	RT	400F	600F	
Ti-6Al-4V	A	L	2.0	296	250	190	172	200
	C	L	2.0		239	193	168	18
	A	T	2.0		257	194		202
	C	T	2.0		255			196
	A	L	1.5		208			166
	C	L	1.5		210			163
Ti-8Al-1Mo-1V	F	L	2.0	282	240	185	167	192
	H	L	2.0		221	172	152	184
	F	T	2.0		249	192		201
	H	T	2.0		268			227
	F	L	1.5		201			161
	H	L	1.5		186			155
Ti-6Al-6V-2Sn	L	L	2.0	329	279	224	205	199
	N	L	2.0		254	218	201	190
	L	T	2.0		290	222		207
	N	T	2.0		270			197
	L	L	1.5		231			165
	N	L	1.5		223			166

[1] Average of three tests

TABLE XI SHEAR STRENGTH OF TITANIUM ALLOY EXTRUSIONS (1)

Description			Shear Strength at Temperature, ksi				Percent of TUS at RT
Alloy	Piece	Direction	-110F	RT	400F	600F	
Ti-6Al-4V	A	L	106	92	77	70	65
	C	L		91	77	70	62
	A	T		92			65
	C	T		92	76.3		63
Ti-8Al-1Mo-1V	F	L	102	91	79	69	65
	H	L		87	(2)	68	64
	F	T		87			63
	H	T		88	75		66
Ti-6Al-6V-2Sn	L	L	119	101	90	81	64
	N	L		101	(2)	83	67
	L	T		102			64
	N	T		100	88		66

(1) Average of three tests

(2) Results not tabulated because of abnormal bending

0.1 percent creep is 1000 hours. Ti-6Al-4V showed 0.1 percent creep in 1000 hours at stress levels 10 percent above yield. Ti-6Al-6V-2Sn showed more susceptibility, with approximately 0.2 percent creep indicated after 500 hours exposure, and approximately 0.4 percent in 1000 hours.

At 800°F creep becomes significant in all alloys. As at all other temperatures, Ti-8Al-1Mo-1V showed the highest degree of resistance, while Ti-6Al-6V-2Sn showed most susceptibility.

Creep tests conducted under conditions of rapid heating and rapid loading result in higher strains than those produced by standard creep exposures, except for Ti-6Al-6V-2Sn. Results of these tests would indicate the desirability of further testing in this area because of the close relationships between this type test and occasional extreme exposure. Relationships between creep under conditions of rapid heat and load compared with creep under standard conditions are shown in Table XII.

Creep data are susceptible to scatter because of minor variations in test procedure and considerable scatter is shown in the data obtained in this program. This does not, within this program, affect interpretation of results.

IMPACT PROPERTIES

Results of Charpy impact tests indicate generally higher values for transverse specimens than for longitudinal specimens at all temperatures. This does not seem reflected in any other properties, but could be due to the notch occur-

TABLE XII COMPARISON OF CREEP STRAIN
UNDER VARYING LOADING CONDITIONS

Alloy	Temp	Stress (Ksi)	Creep Strain in/in					
			Rapid Heat And Load			Standard Creep		
			5 min	30 min	60 min	1 hr	100 hr	500 hr
Ti-6Al-4V	600F	71	0.0012	0.0017	0.0018			
		79	0.0006	0.0022	0.0029	0.0006		0.0027
		85	0.0007	0.0020	0.0030			
		89				0.0006	0.0009	0.0010
	800F	58	0.0004	0.0010	0.0012			
		65	0.0005	0.0007	0.0007			
		75	0.0004	0.0018	0.0028	0.0014	0.0183	
Ti-8Al-1Mo-1V	600F	81	0.0004		0.0006	0.0004	0.0005	0.0006
	800F	58	0.0002	0.0008	0.0010			
		72	0.0003	0.0006	0.0007	0.0003	0.0028	0.005
		85	0.0008	0.0017	0.0020	0.0006	0.0046	0.008
Ti-6Al-6V-2Sn	600F	90						
		100	0.0004	0.0006	0.0006	0.0004	0.0016	0.0024
		112	0.0009	0.0018	0.0018	0.0006	0.0024	
	800F	69	0.0008	0.0029	0.0048			
		88	0.0015	0.0067	0.0105			
		98	0.0059	0.0242	0.0428			

ring in the junction area. Impact toughness varies inversely with alloy strength as expected. The tests at minus 110F represent specimens machined and tested separately from other specimens and, therefore, are considered to represent a variable in test rather than a reversal of trend in impact properties. Test results are shown in Figures 40, 41, and 42.

FRACTURE TOUGHNESS AND DELAYED FAILURE

K_{Ic} fracture toughness values at -110°F and at room temperature, along with delayed failure characteristics are given in Table XIII. Values obtained in this program agree within expected scatter with values obtained on similar material evaluated as part of recent programs at Lockheed, and are less than scatter observed in heavy products such as forgings. Ti-8Al-1Mo-1V presents the most favorable fracture toughness characteristics, but appears to have slightly inferior delayed failure characteristics. Delayed failure of Ti-8Al-1Mo-1V extrusions, air-cooled, appear to be superior to past values obtained using furnace-cooled materials and are above values obtained in the past on annealed bar worked in the alpha-beta field.

Figures 43, 44, and 45 depict delayed failure as a function of time.

FATIGUE

Results of the fatigue tests on the three titanium alloys tested are presented as S/N curves in Section V. Figure numbers of curves are as follows:

Alloy	K_T	A	Temp	Fig. No.
Ti-6Al-4V	1.0	0.98	RT	54
	2.76	∞,0.98,0.4	RT	55
	2.76	∞,0.98,0.4	400°F	56
	2.76	∞,0.98.0.4	600°F	57
Ti-8Al-1Mo-1V	1.0	0.98	RT	66
	2.76	∞,0.98,0.4	RT	67
	2.76	∞,0.98,0.4	400°F	68
	2.76	∞,0.98,0.4	600°F	69
Ti-6Al-6V-2Sn	1.0	0.98	RT	78
	2.76	∞,0.98,0.4	RT	79
	2.76	∞,0.98,0.4	400°F	80
	2.76	∞,0.98,0.4	600°F	81

Fatigue characteristics of the three alloys were considered to be similar in the same scatter band. Values were intermediate in relation to those seen in previous evaluations of extruded products. Values appear to be below those shown in MIL-HDBK-5, but do not appear to be below typical values seen in other programs on heavy sections such as bar, plate, or forgings.

Material from one vendor tends to show slightly higher fatigue values than that of the other. At this time, this is considered to represent random scatter

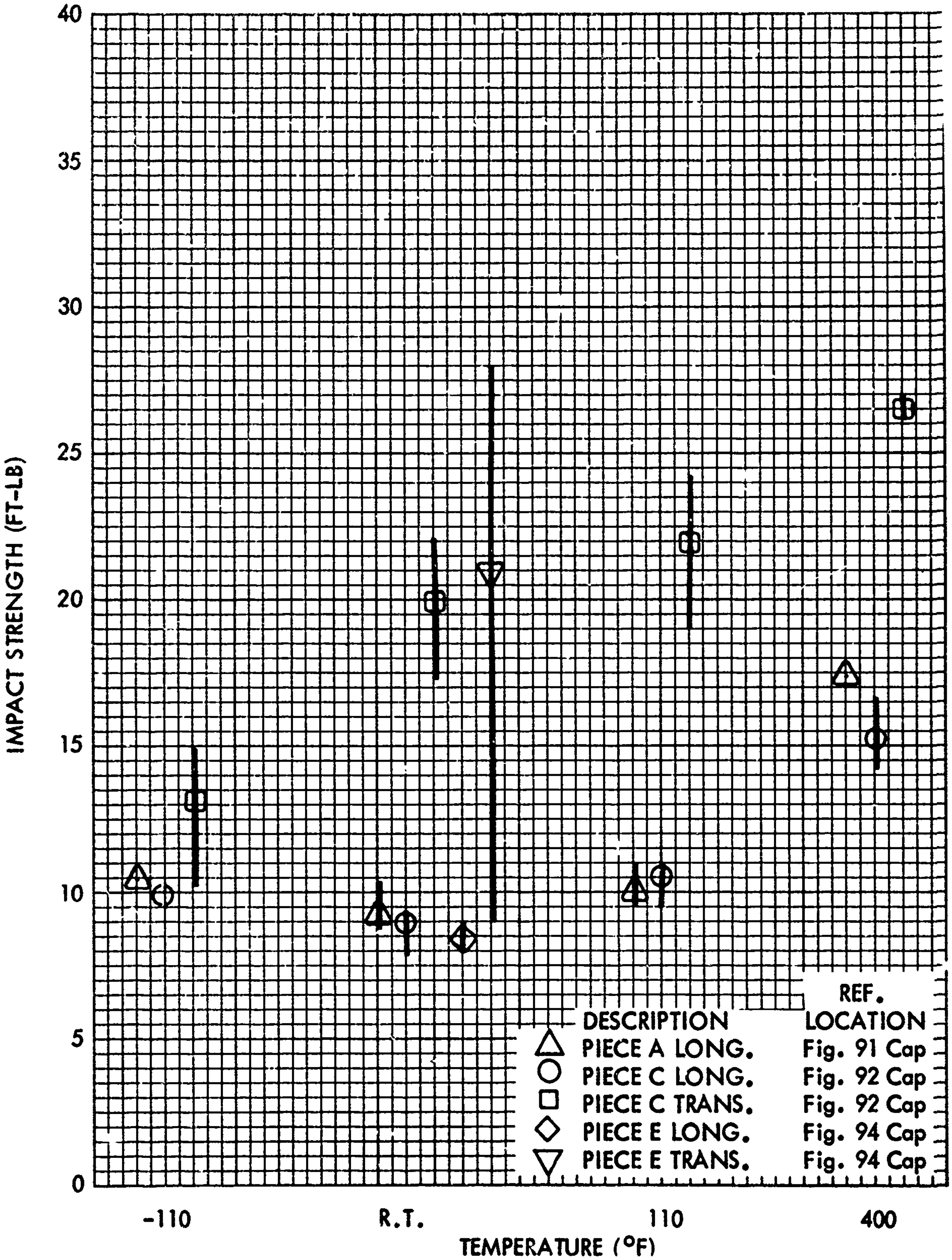


Figure 40. Charpy Impact Properties of Ti-6Al-4V Extrusions

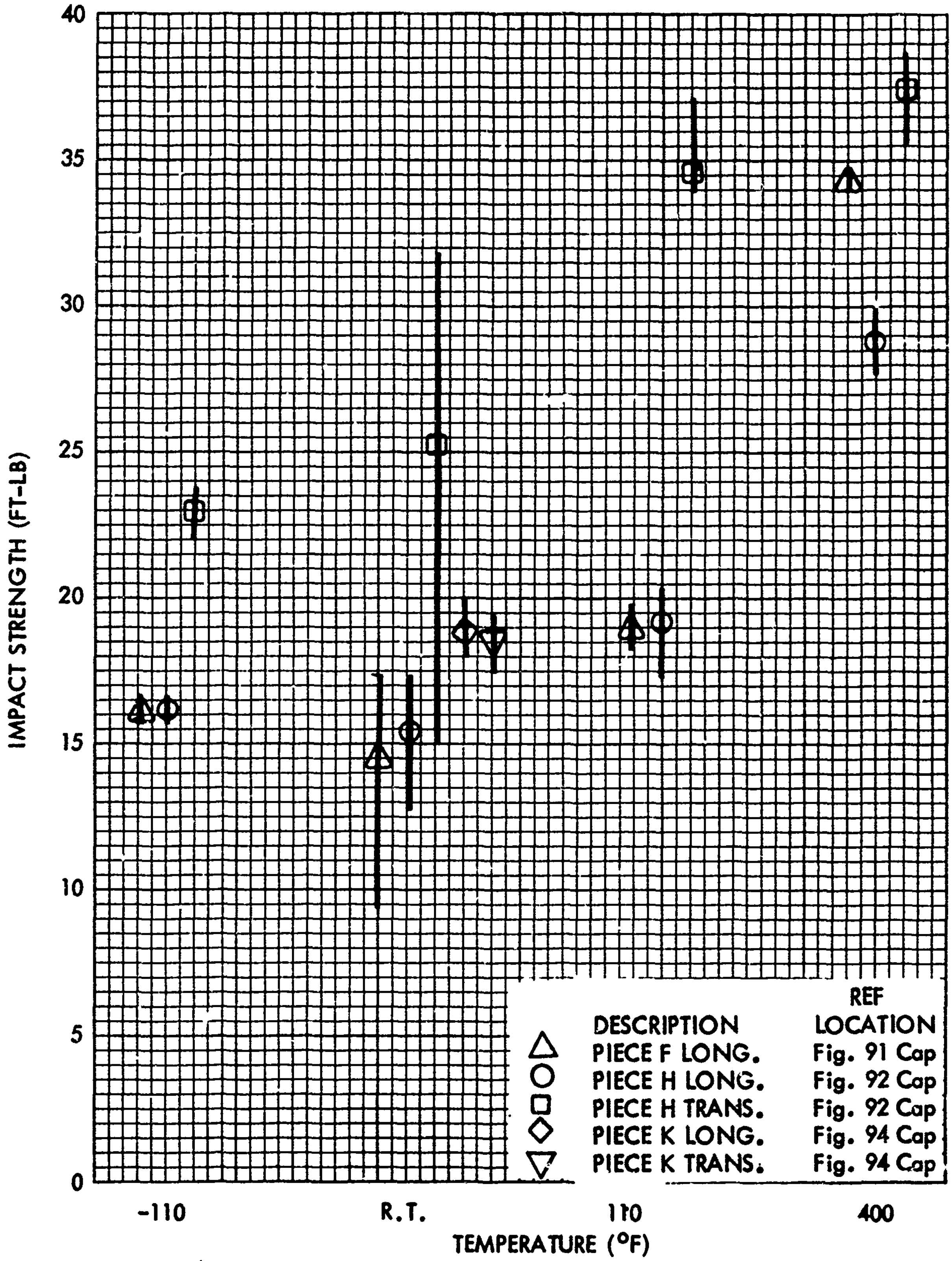


Figure 41. Charpy Impact Properties of Ti-8Al-1Mc-1V Extrusions

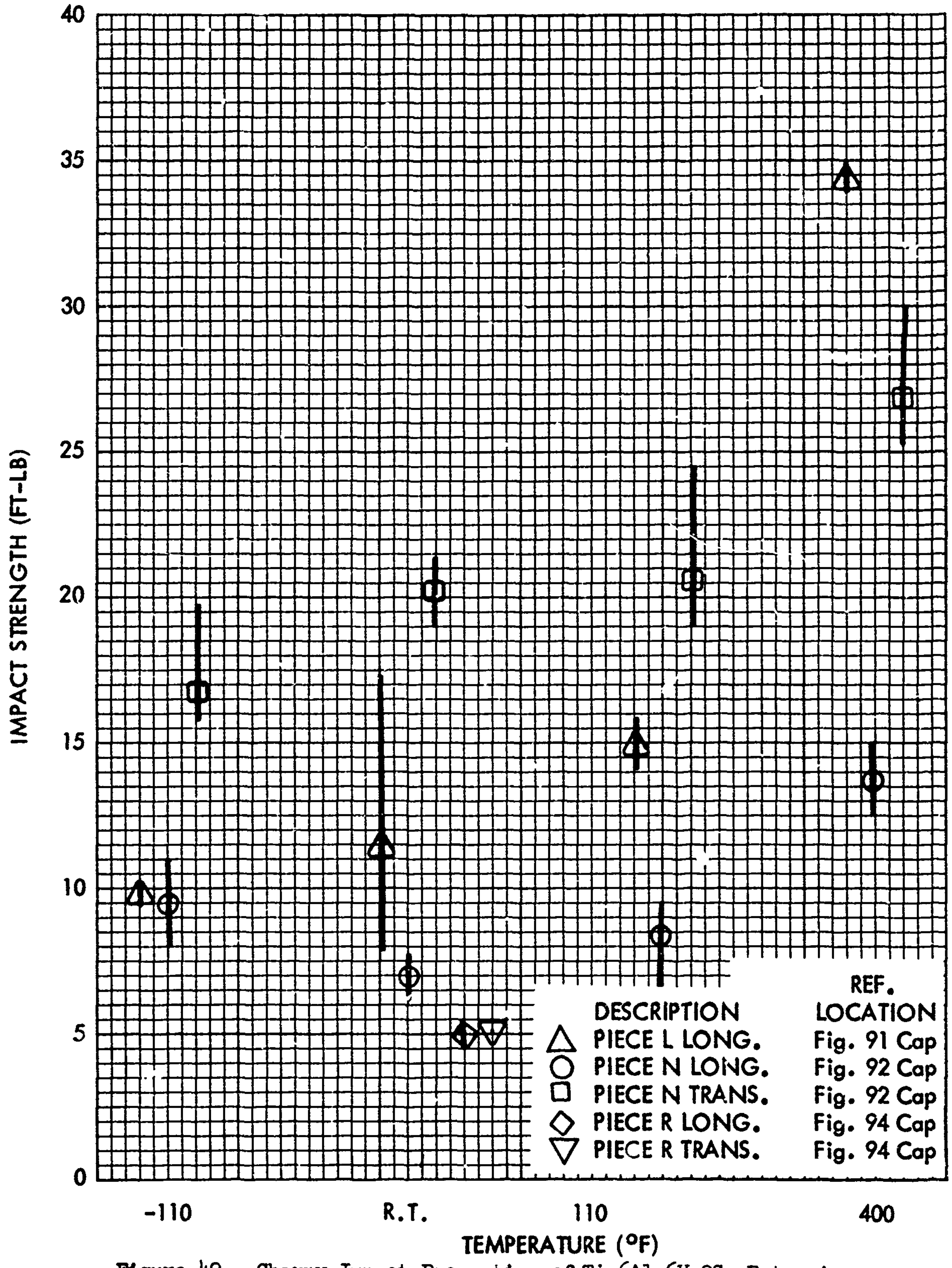


Figure 42. Charpy Impact Properties of Ti-6Al-6V-2Sn Extrusions

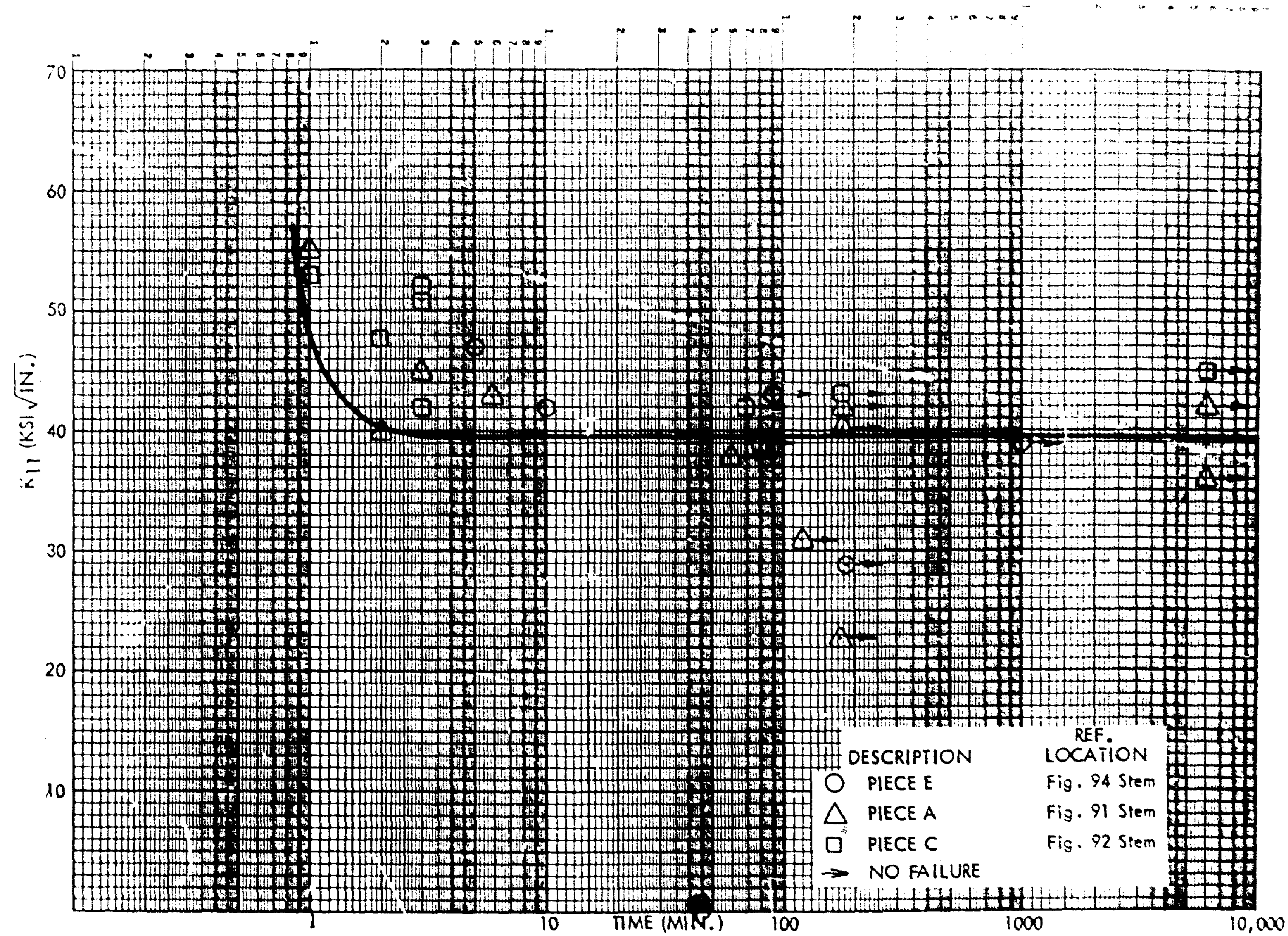


Figure 43. Delayed Failure Characteristics of Ti-6Al-4V Extrusions

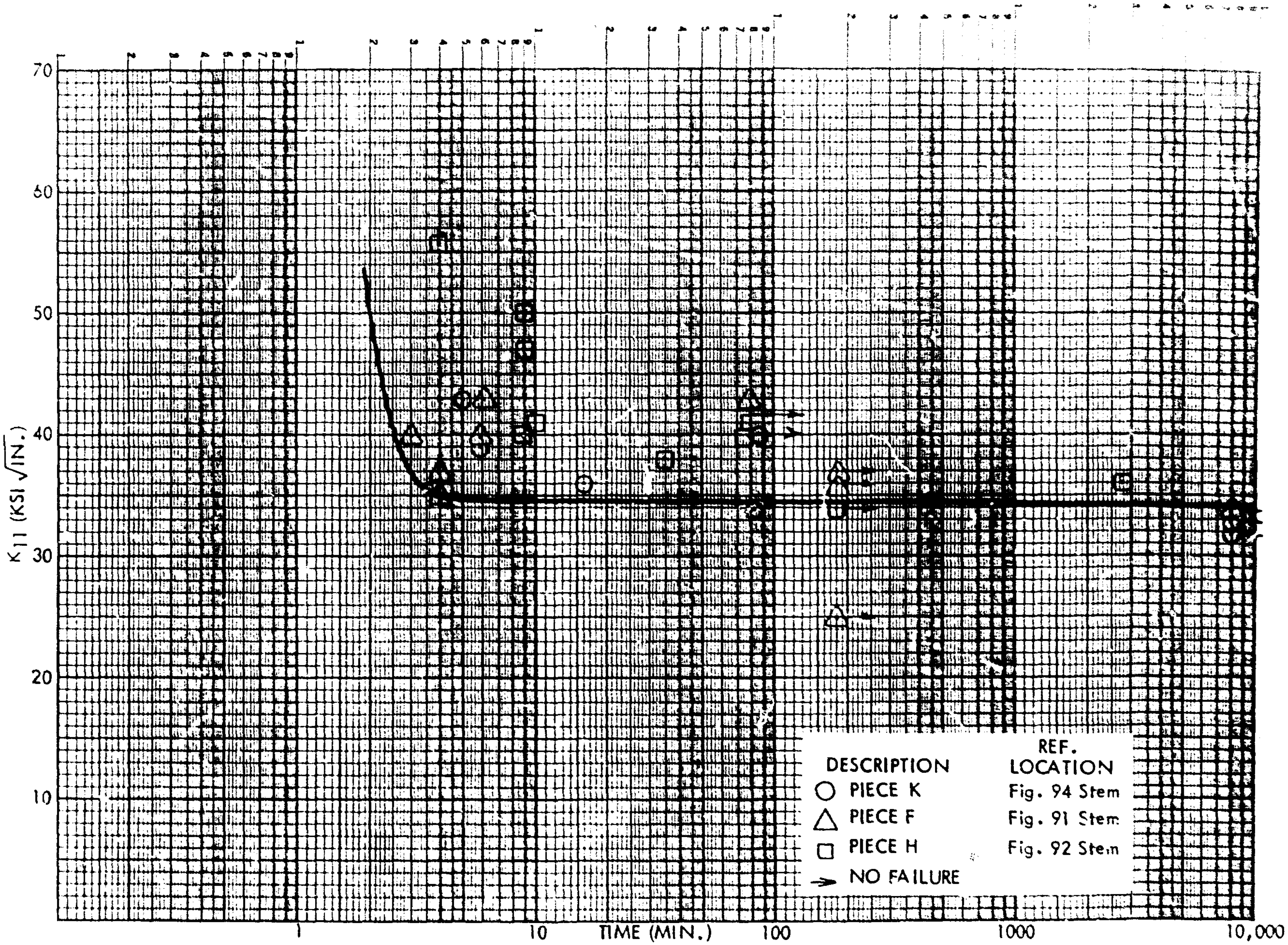


Figure 44. Delayed Failure Characteristics of Ti-8Al-1Mo-1V Extrusions

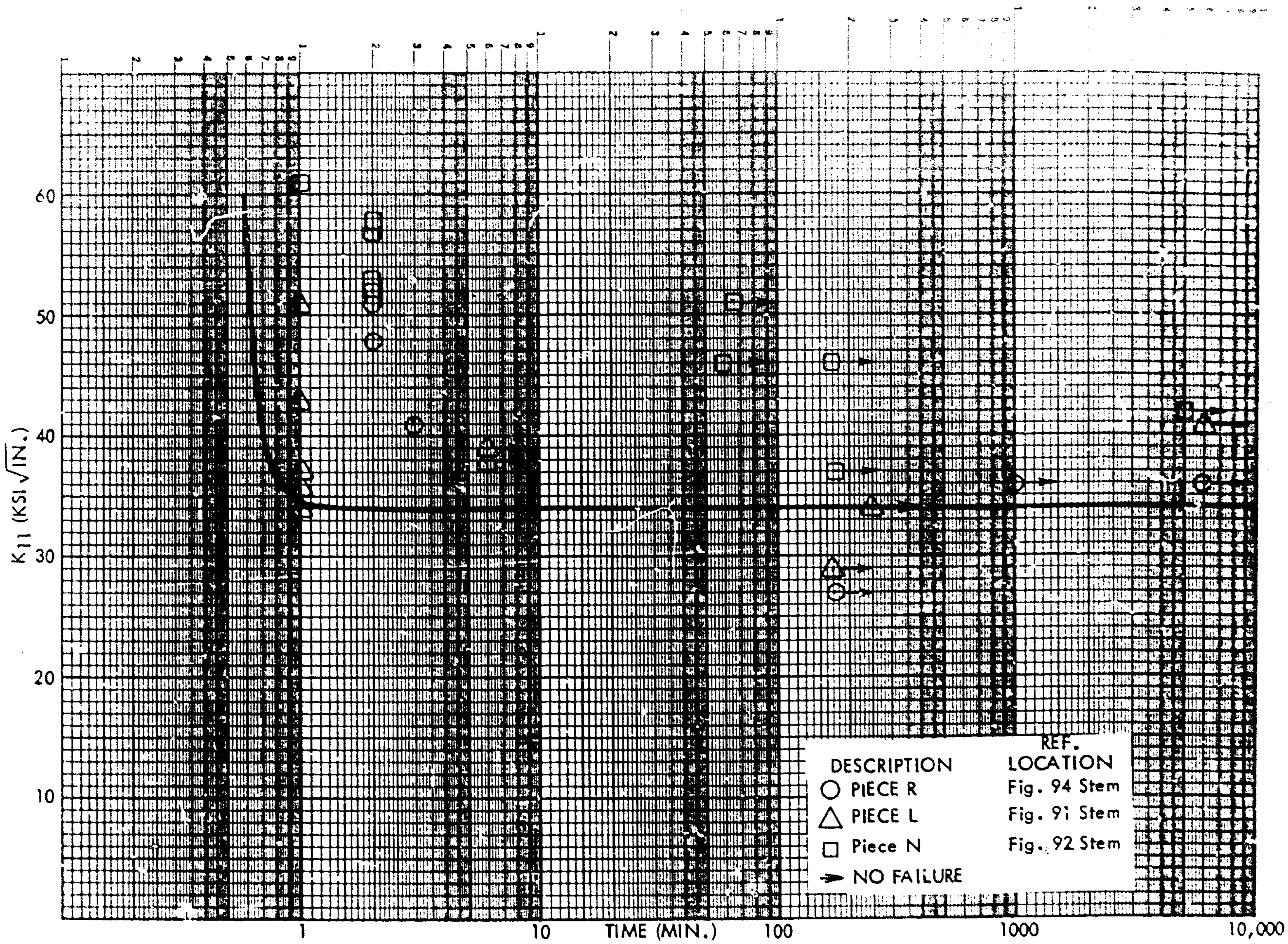


Figure 45. Delayed Failure Characteristics of Ti-6Al-6V-2Sn Extrusions

TABLE XIII FRACTURE TOUGHNESS AND DELAYED FAILURE CHARACTERISTICS OF TITANIUM ALLOY EXTRUSIONS

Alloy	Piece	Grain Direction	K_{Ic} (ksi $\sqrt{in.}$)		K_{Ii} (ksi $\sqrt{in.}$)	
			-110F	RT	Held	Failed
Ti-6Al-4V	A	L	68	73	36	40
	C	L	63	65	45	48
	E	L		79	39	42
Ti-8Al-1Mo-1V	F	L	76	83	34	35
	H	L	88	88	34	36
	K	L		85	34	36
Ti-6Al-6V-2Sn	L	L	46	58	29	34
	N	L	56	72	42	57
	R	L		58	36	41

until effect of processing variables on fatigue can be determined through other programs.

Elevated temperatures seem to affect only the high-cycle end of the fatigue curves. Alloys Ti-6Al-4V and Ti-8Al-1Mo-1V seem to see more effect than Ti-6Al-6V-2Sn. This trend has been observed on previous programs.

Modified Goodman diagrams prepared from data obtained in this program are presented in Figures 58, 59, 72, 73, 86 and 87.

Section V

PRELIMINARY DESIGN INFORMATION

Tentative design properties for extruded titanium alloys Ti-6Al-4V, Ti-8Al-1Mo-1V, and Ti-6Al-6V-2Sn in the Annealed tempers are presented in this Section. Current specifications for these products are not established on a government nor an industry basis*. Design properties are indicated as tentative until such time as sufficient depth of data (and corresponding modifications) to meet MIL-HDBK-5 standards are compiled and incorporated.

Ti-6Al-4V TENTATIVE DESIGN PROPERTIES

(1) Tentative room temperature design mechanical properties are summarized in Table XIV.

(2) Effect of temperature on ultimate tensile strength at temperature is shown in Figure 46. Effect of temperature on tensile yield strength is shown in Figure 47. Effect of temperature on compressive yield strength is shown in Figure 48. Effect of temperature on shear and on bearing properties are shown in Figures 49, 50, and 51.

(3) Stress-strain curves in tension and compression (typical curves) are shown in Figures 52 and 53.

(4) S/N diagrams showing typical room temperature and elevated temperature fatigue characteristics of smooth and of notched specimens are shown in Figures 54, 55, 56, and 57, modified Goodman diagrams in Figures 58 and 59.

(5) Discussion of fracture toughness, and of delayed failure characteristics is included in Section IV.

(6) Discussion of fracture toughness, and of delayed failure characteristics is included in Section IV.

Ti-8Al-1Mo-1V TENTATIVE DESIGN PROPERTIES

(1) Tentative room temperature design mechanical properties are summarized in Table XV.

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*AMS4935 in its present form (Revision A) is not normally used without exceptions.

Table XIV Tentative Design Mechanical and Physical Properties of Ti-6Al-4V Titanium Alloy (Extrusions)

Alloy	Ti-6Al-4V
Form	Extruded Shapes, Rod and Bar
Condition	Annealed
Thickness or diameter, in.	All
Basis	S
Mechanical properties:	
F_{tu}, ksi	
L	135
LT	135
F_{ty}, ksi	
L	125
LT	125
F_{cy}, ksi	(Typical Values Shown in Table IV)
L	
LT	
F_{su}, ksi	(Typical Values Shown in Table XI)
F_{bru}, ksi:	(Typical Values Shown in Table IX)
(e/D = 1.5)	
(e/D = 2.0)	
F_{bry}, ksi:	(Typical Values Shown in Table X)
(e/D = 1.5)	
(e/D = 2.0)	
e, per cent:	
In 2 in.	10
In 4 D	10
E, 10^6 psi	16.9
E_c, 10^6 psi	
G, 10^6 psi	
μ	
Physical properties:	
ω, lb/in.^{3}	0.160
C, Btu/(lb)(F)	
K, Btu/[(hr)(ft^2)(F)/ft]	
α, 10^{-6} in./in./F	

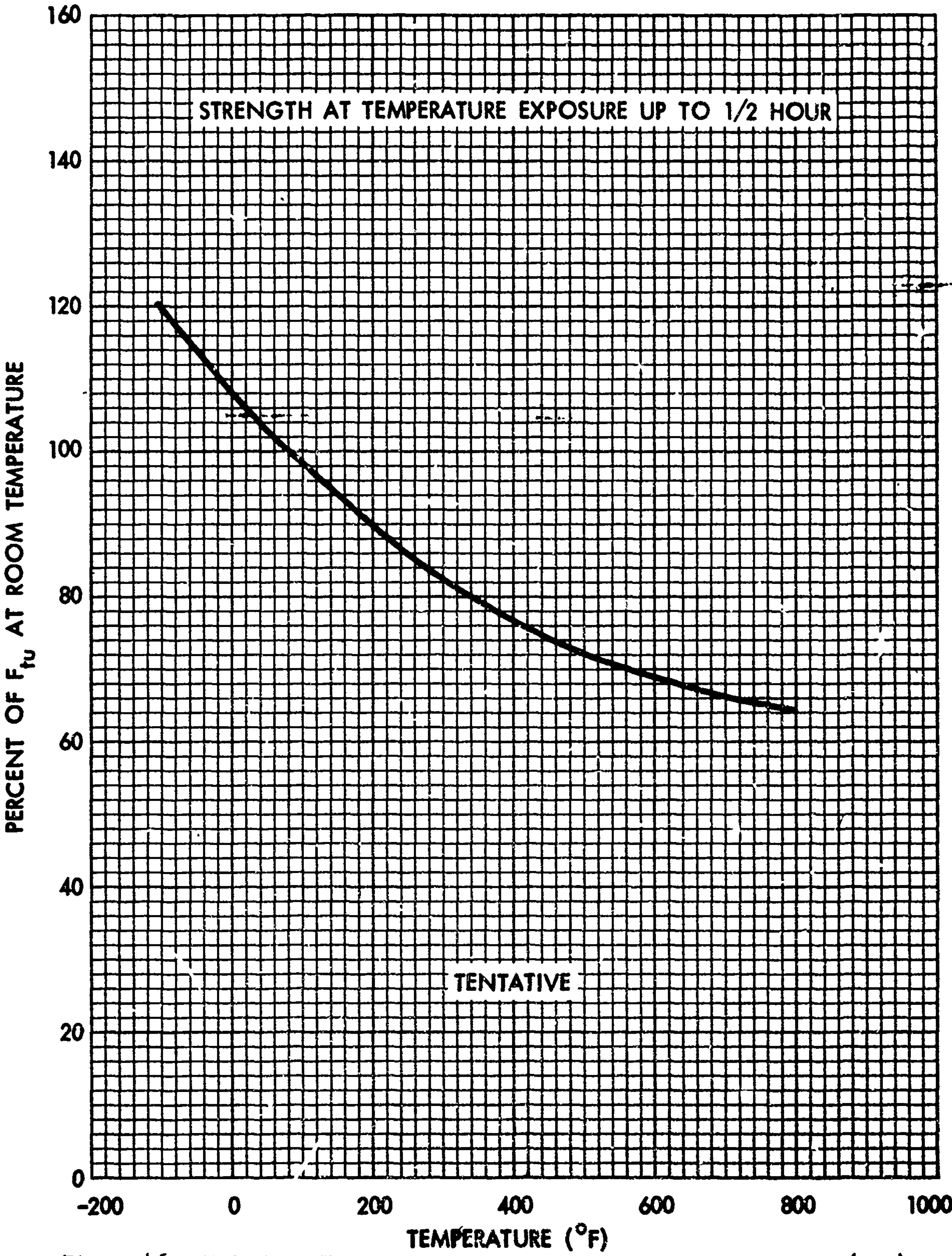


Figure 46. Effect of Temperature on the Ultimate Tensile Strength (F_{tu}) of Annealed Ti-6Al-4V Extrusions

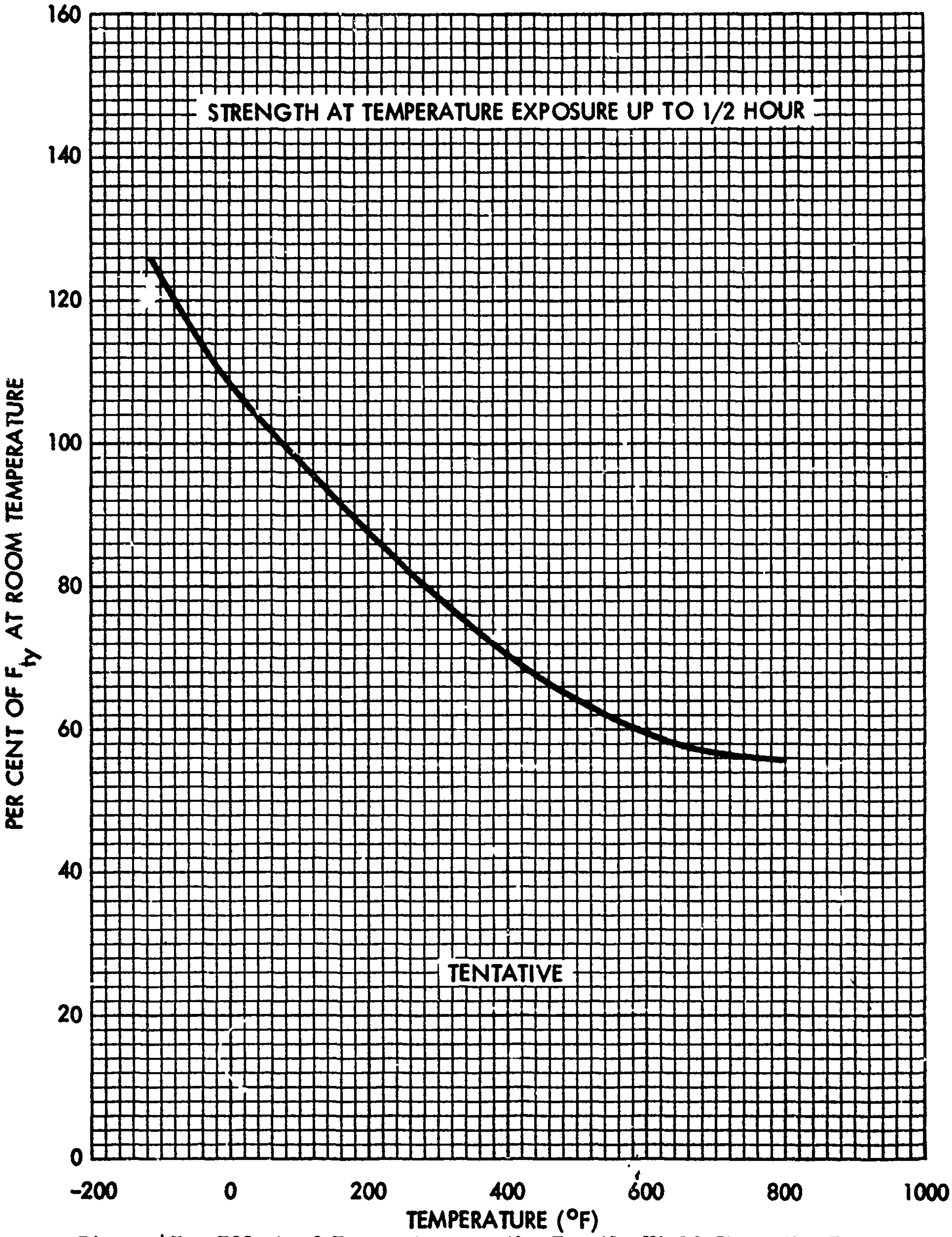


Figure 47. Effect of Temperature on the Tensile Yield Strength (F_{cy}) of Annealed Ti-6Al-4V Extrusions

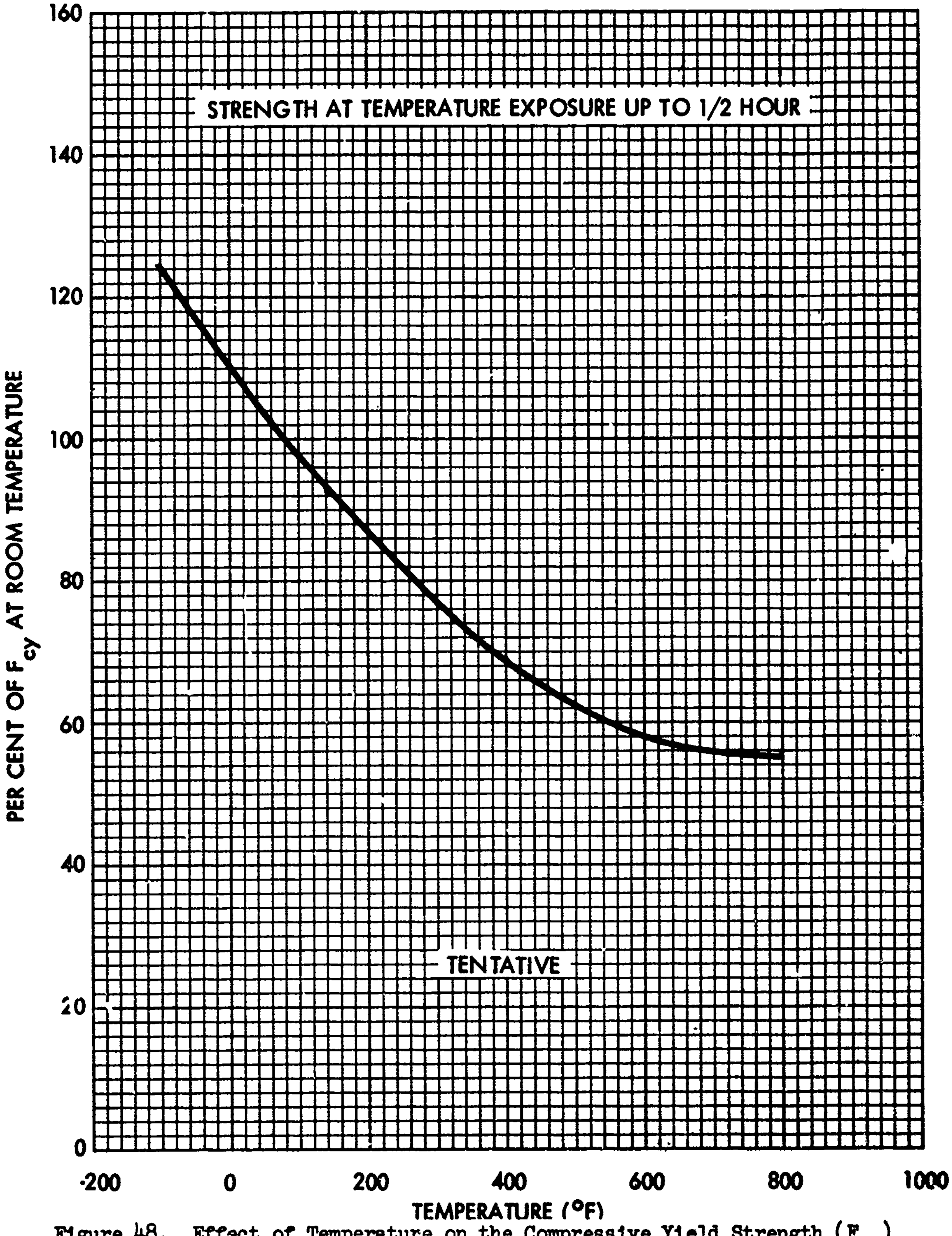


Figure 48. Effect of Temperature on the Compressive Yield Strength (F_{cy}) of Annealed Ti-6Al-4V Extrusions

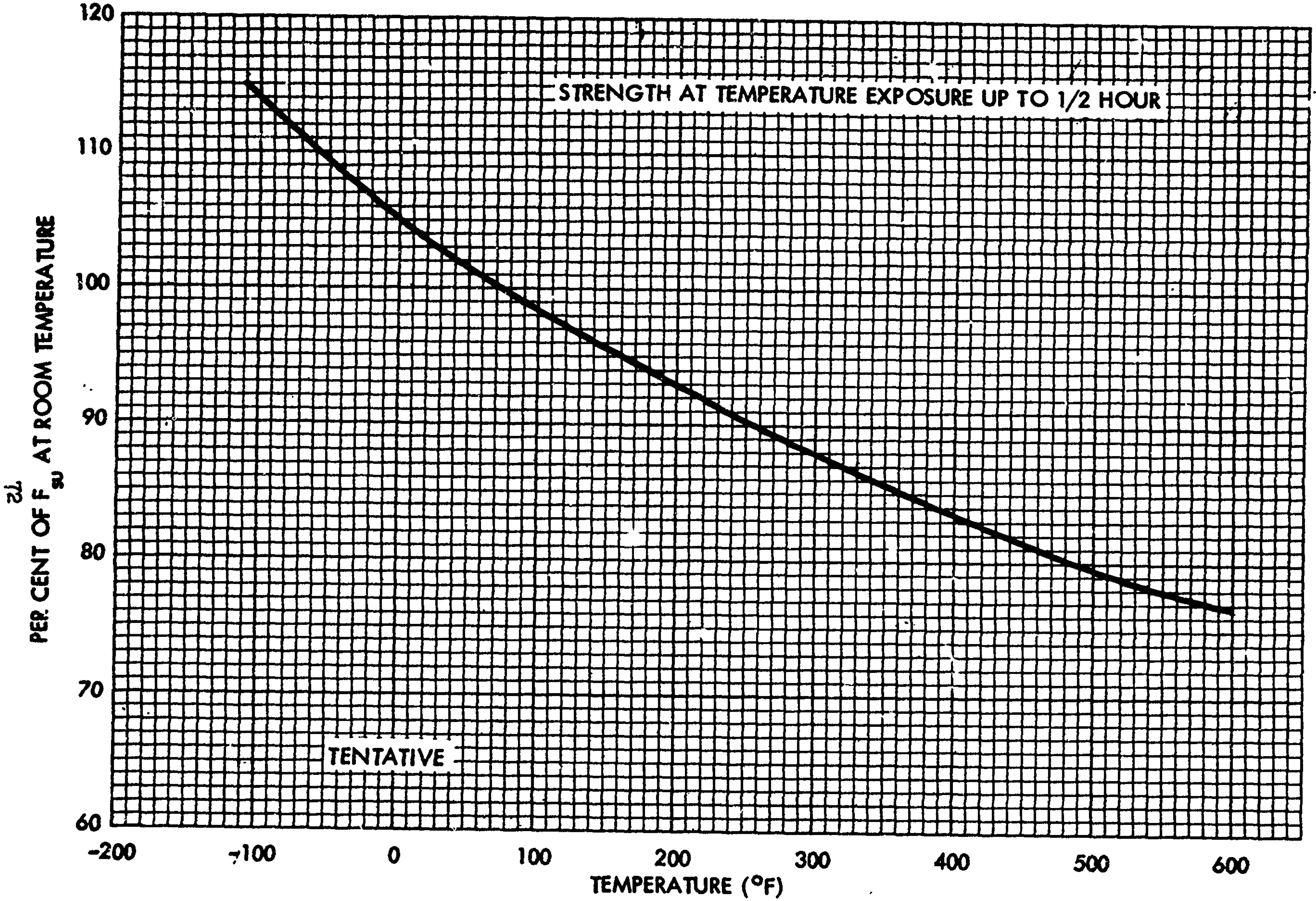


Figure 49. Effect of Temperature on the Ultimate Shear Strength (F_{su}) of Ti-6Al-4V Extrusions

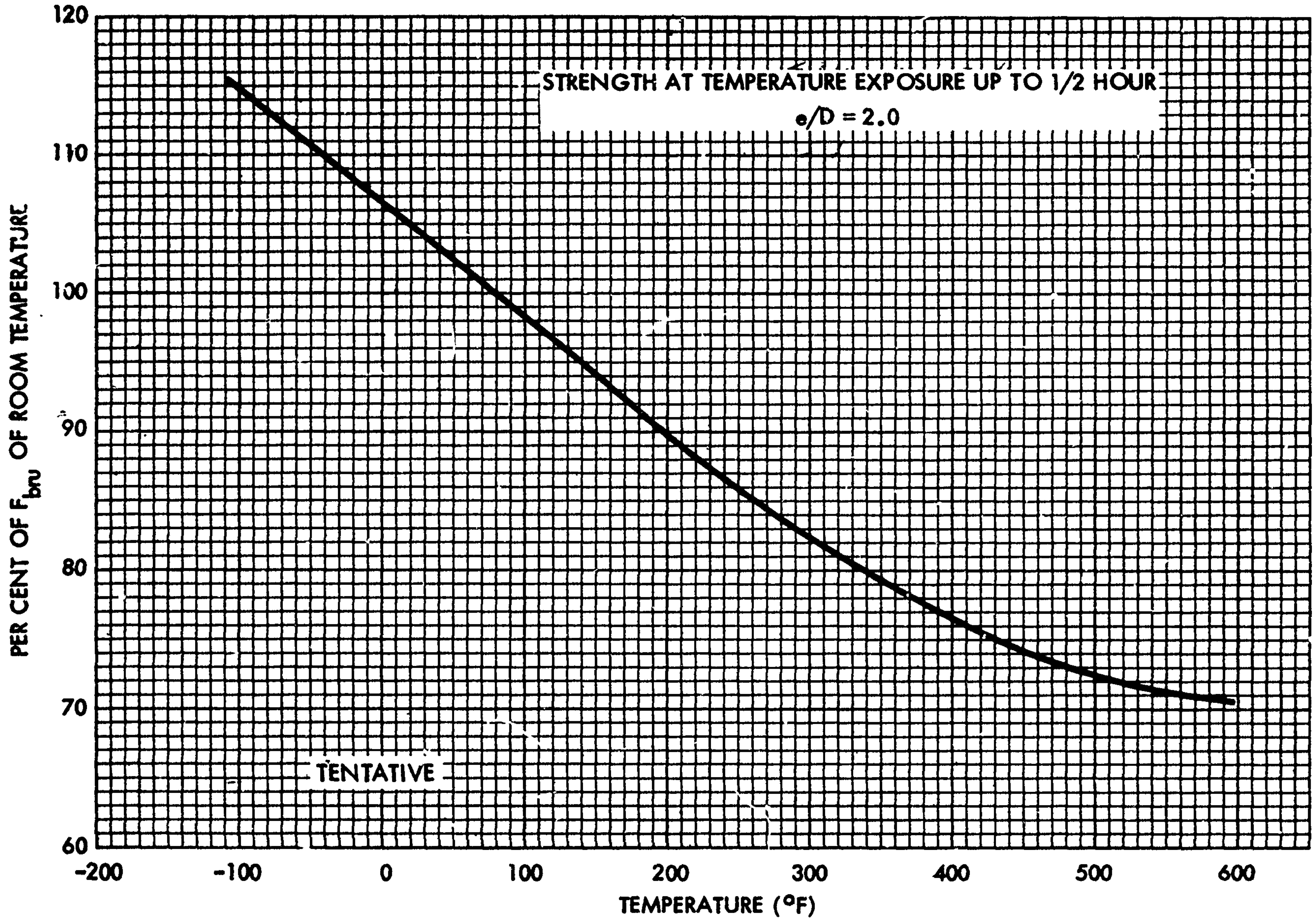


Figure 50. Effect of Temperature on the Ultimate Bearing Strength (F_{bru}) of Ti-6Al-4V Extrusions

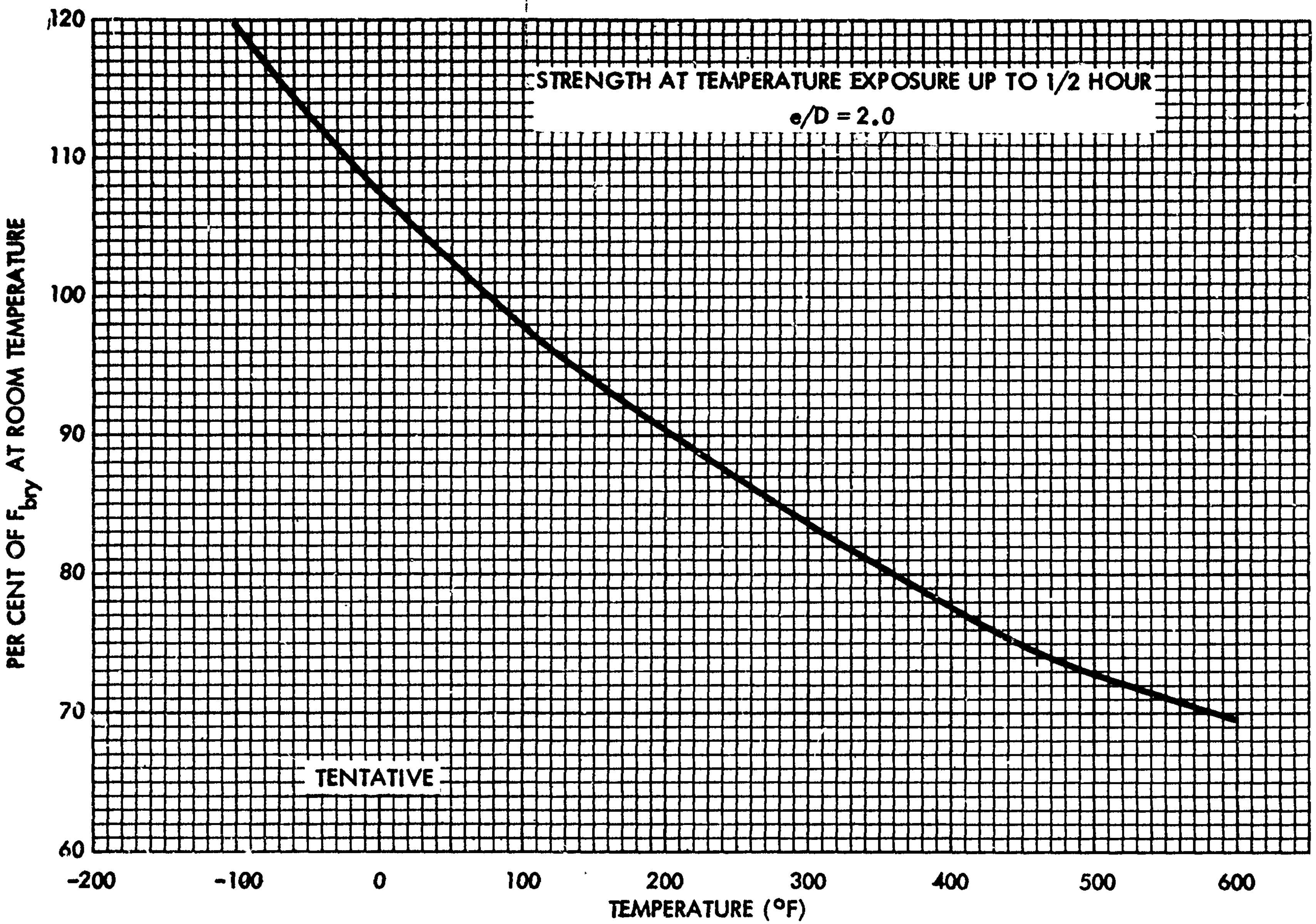


Figure 51. Effect of Temperature on the Bearing Yield Strength (F_{bry}) of Ti-6Al-4V Extrusions

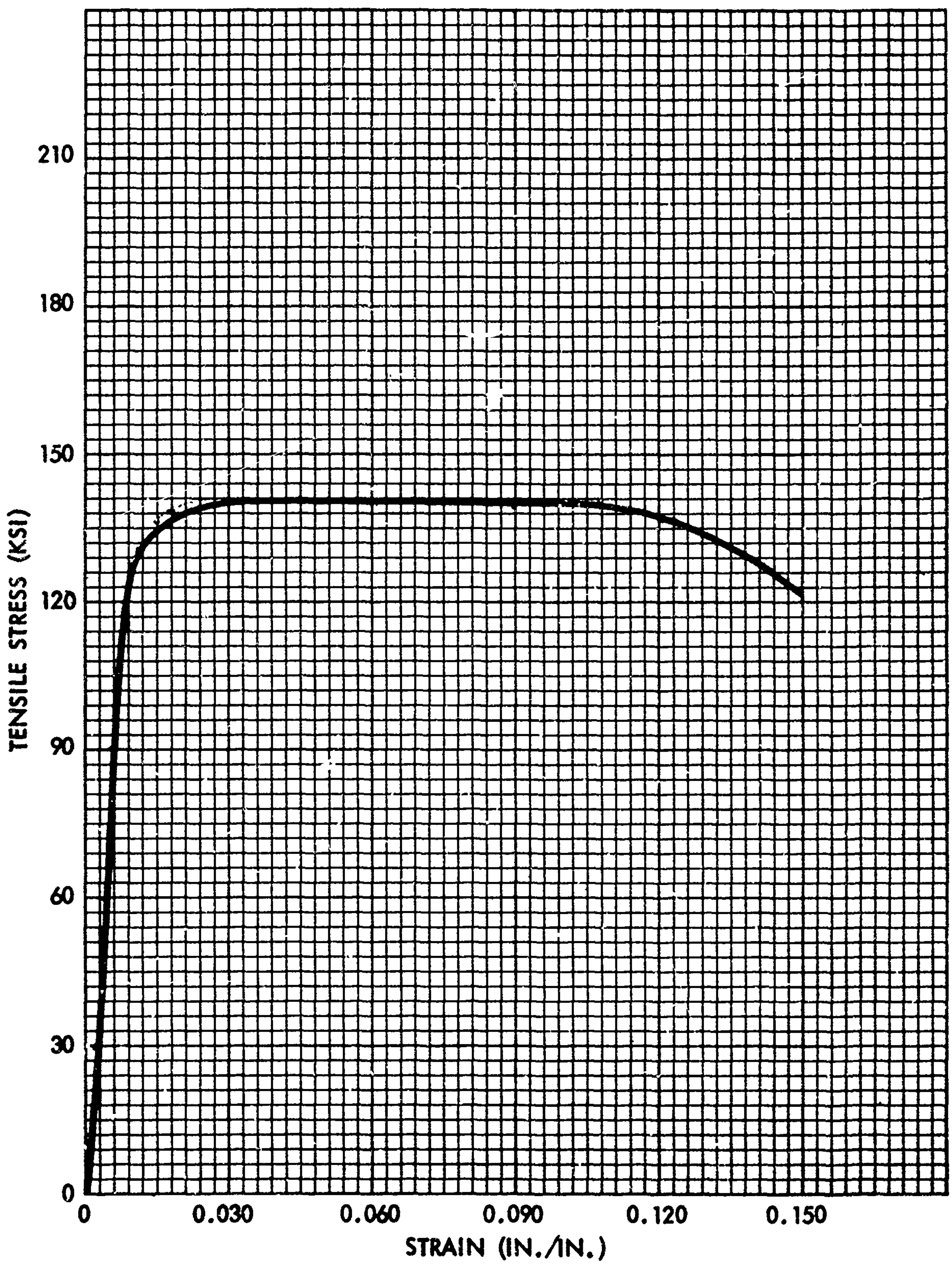


Figure 52. Typical Tensile Stress--Strain Curve Ti-6Al-4V Extrusion at Room Temperature

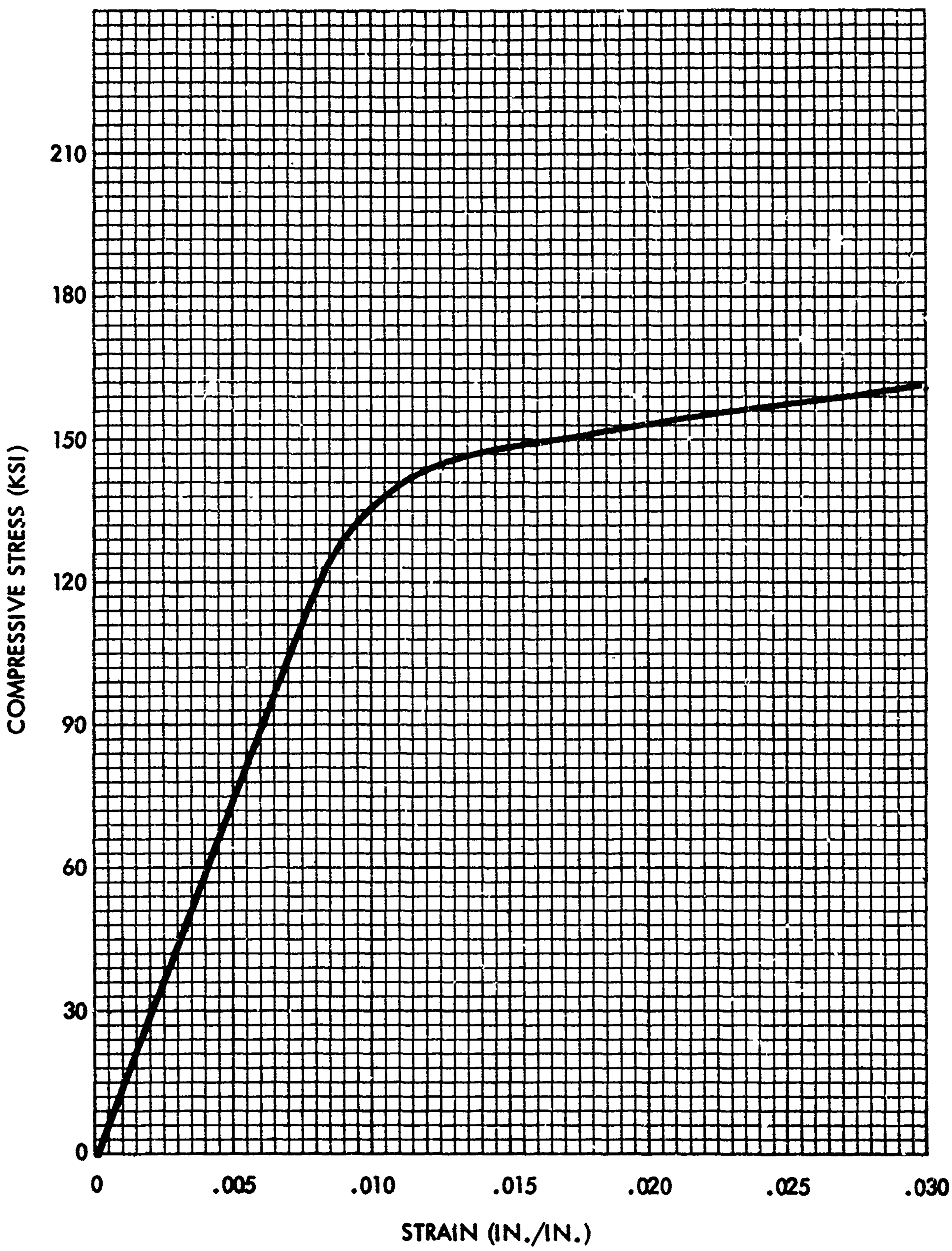


Figure 53. Typical Compressive Stress--Strain Curve Ti-6Al-4V Extrusion at Room Temperature

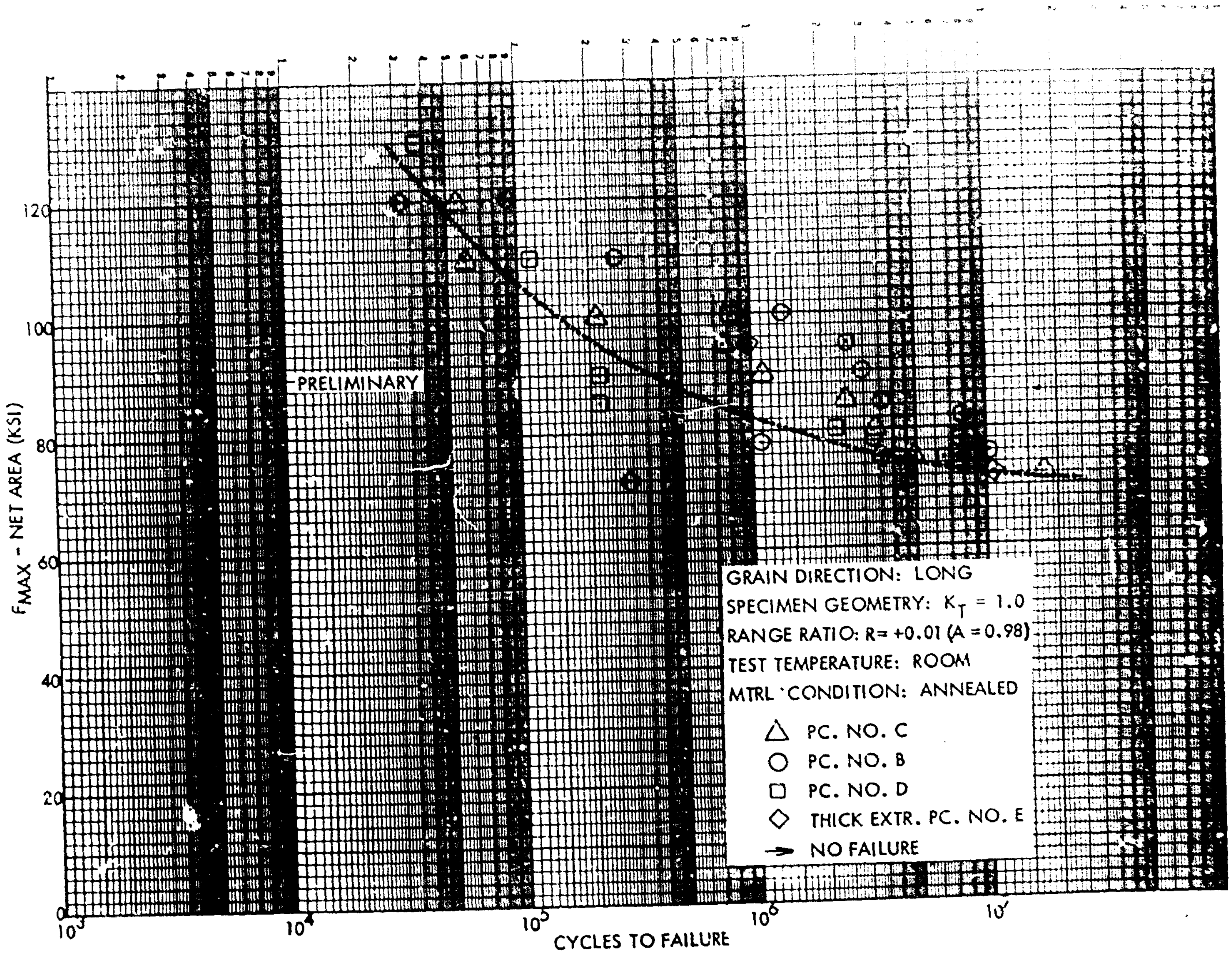


Figure 54. Typical S/N Fatigue Curve for K_T = 1.0, Ti-6Al-4V Extrusions at Room Temperature

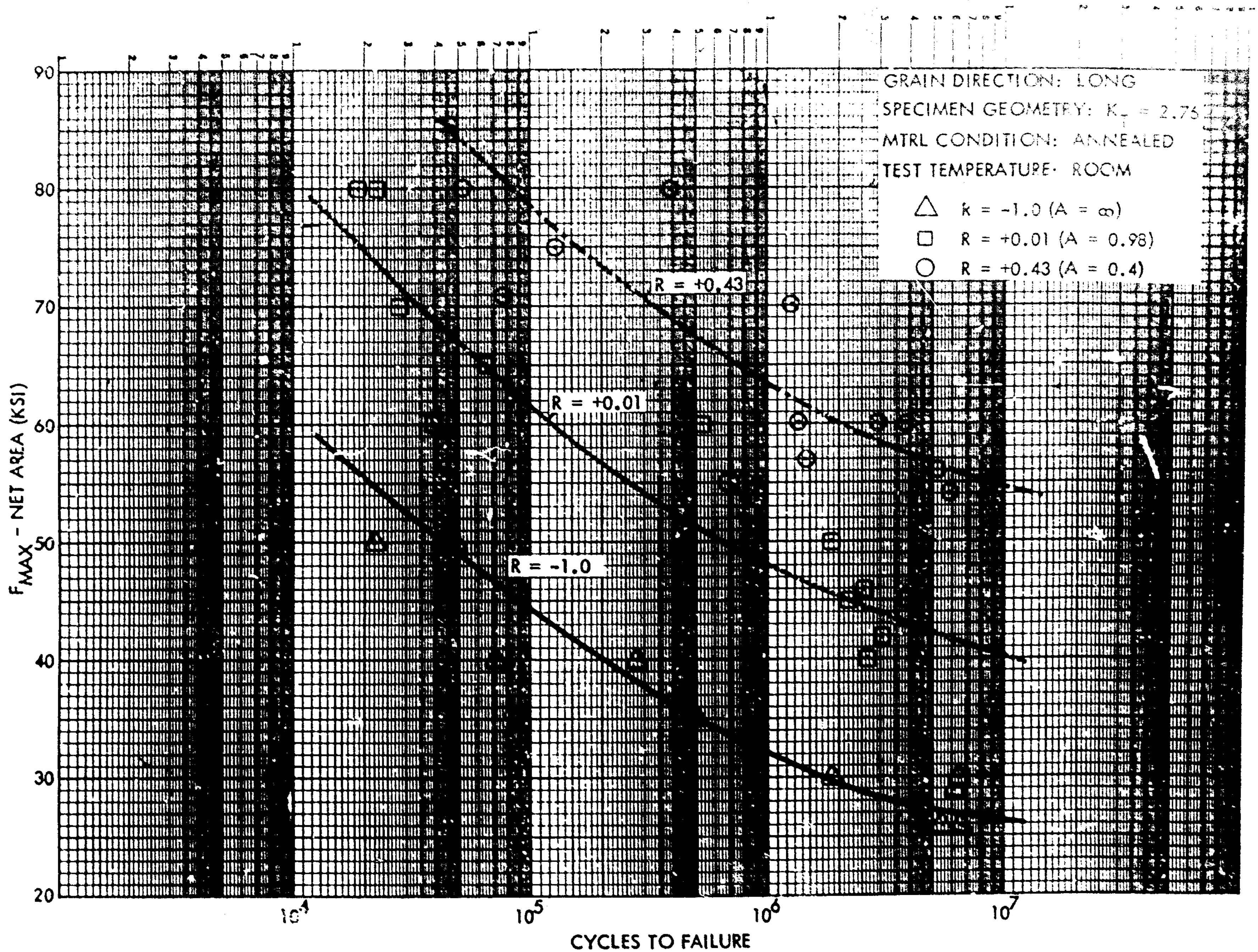


Figure 55. Typical S/N Fatigue Curves for K_T = 2.76 (A = ∞, A = 0.98, A = 0.4), Ti-6Al-4V Extrusions at Room Temperature

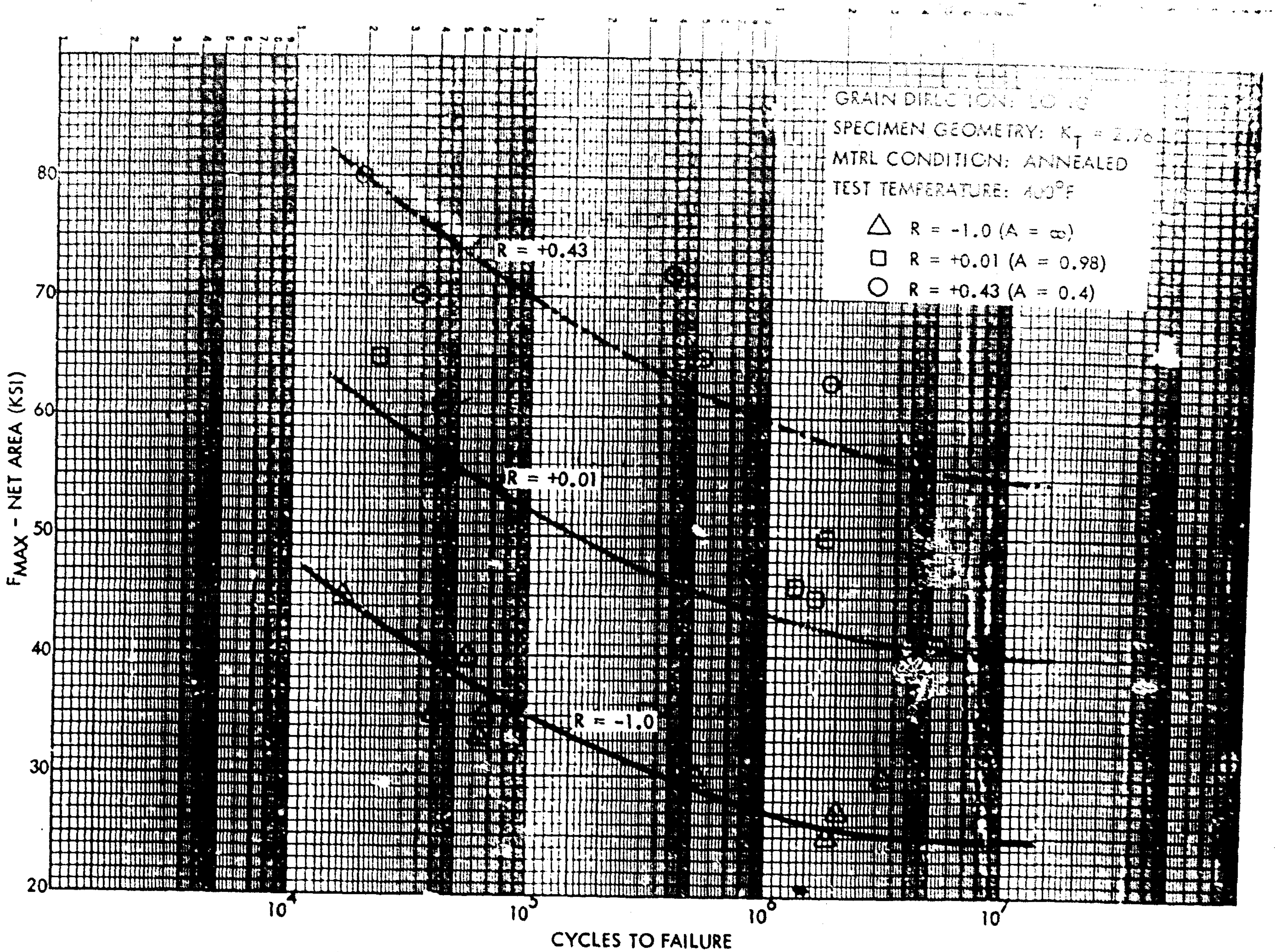


Figure 56. Typical S/N Fatigue Curves for K_T 2.76 ($A = \infty$, $A = 0.98$, $A = 0.4$), Ti-6Al-4V Extrusions at 400F

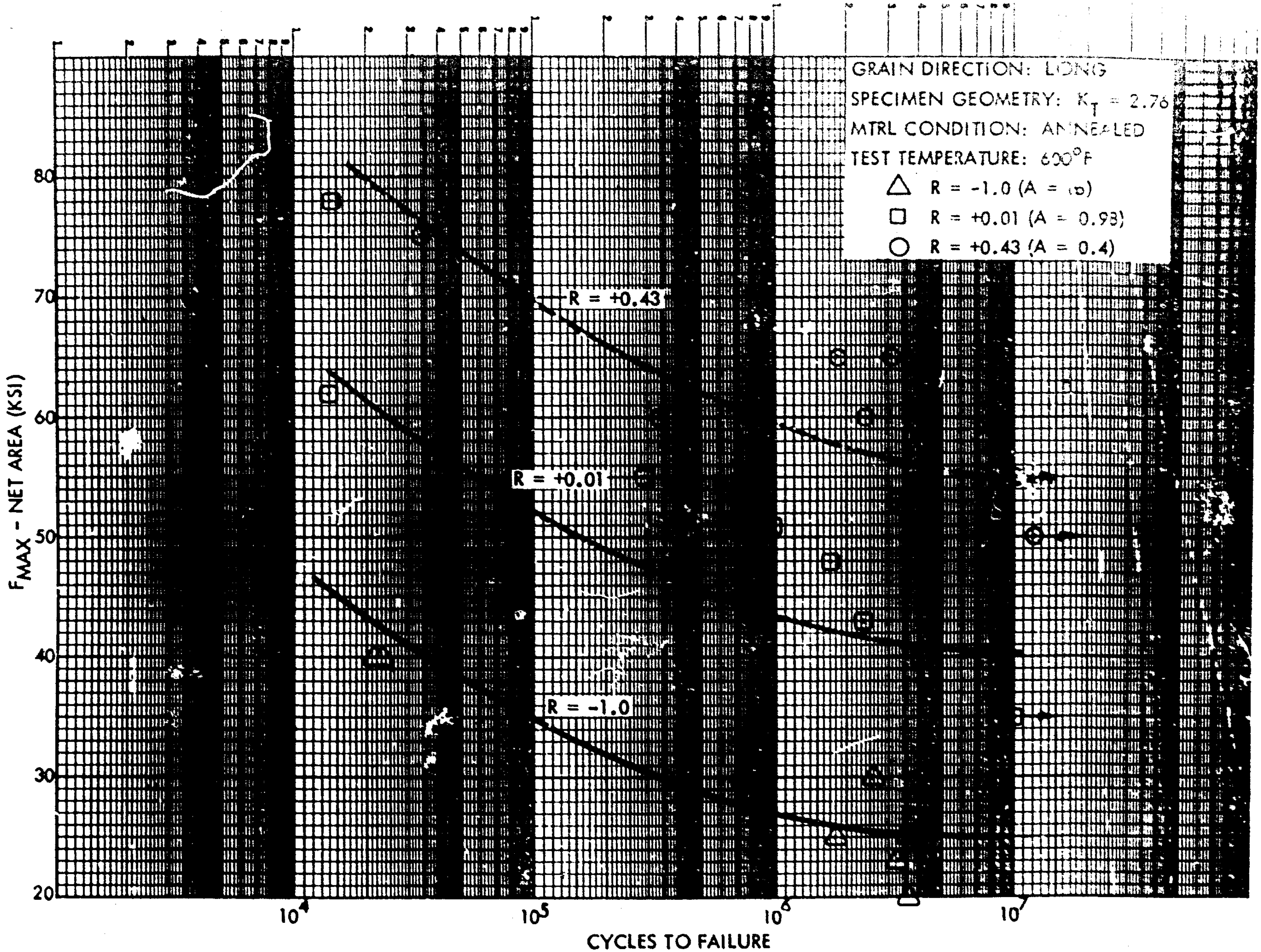


Figure 57. Typical S/N Fatigue Curves for K_T 2.76 (A = ∞, A - 0.98, A - 0.4), Ti-6Al-4V Extrusions at 600F

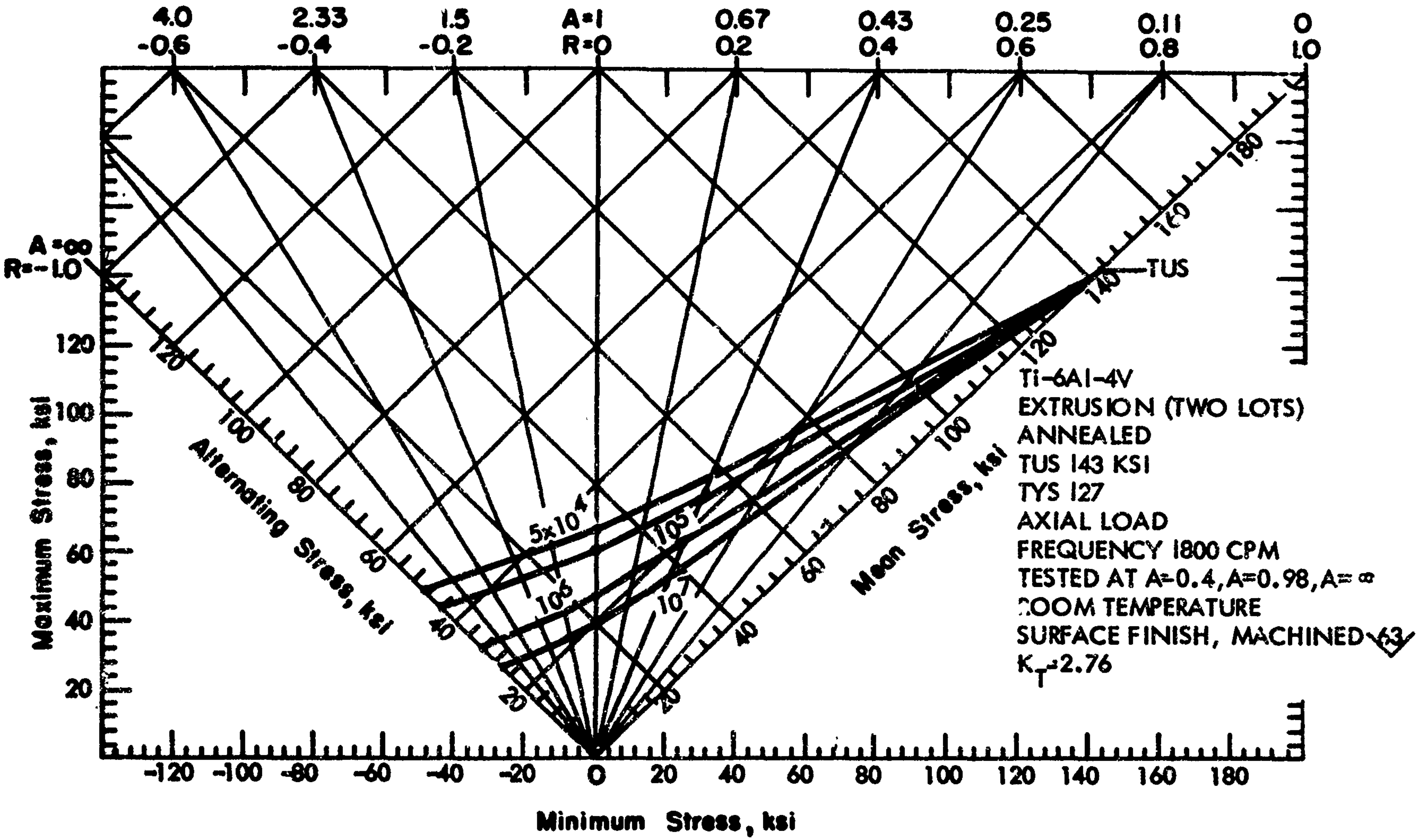


Figure 58. Constant-life Fatigue Diagram for Notched Ti-6Al-4V Annealed Extrusions at Room Temperature

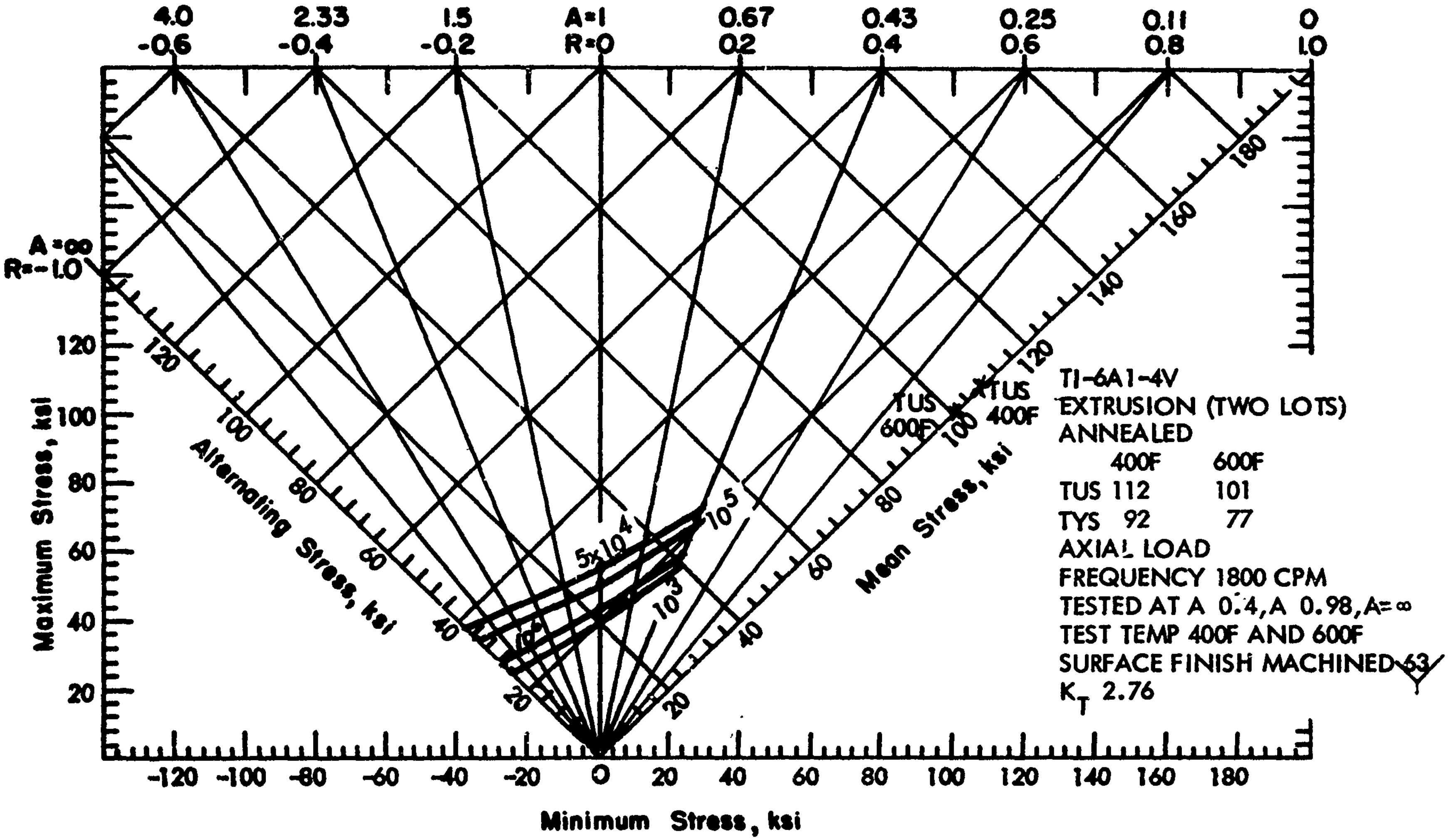


Figure 59. Constant-life Fatigue Diagram for Notched Ti-6Al-4V Extrusions at 400F and 600F

Table XV Tentative Design Mechanical and Physical Properties of Ti-8Al-1Mo-1V Titanium Alloy (Extrusions)

Alloy	Ti-8Al-1Mo-1V
Form	Extruded Shapes, Rod and Bar
Condition	Annealed
Thickness or diameter, in.	
Basis	S
Mechanical properties:	
F_{tu}, ksi	
L	130
LT	130
F_{ty}, ksi	
L	120
LT	120
F_{cy}, ksi	(Typical values shown in Table V)
L	
LT	
F_{su}, ksi	(Typical values shown in Table XI)
F_{bru}, ksi:	
(e/D = 1.5)	(Typical values shown in Table IX)
(e/D = 2.0)	
F_{bry}, ksi:	
(e/D = 1.5)	(Typical values shown in Table X)
(e/D = 2.0)	
e, per cent:	
In 2 in.	10
In 4 D	10
E, 10^6 psi	17.6
E_c, 10^6 psi	
G, 10^6 psi	
μ	
Physical properties:	
ω, lb/in.^{3}	0.158
C, Btu/(lb)(F)	
K, Btu/[(hr)(ft^2)(F)/ft]	
α, 10^{-6} in./in./F	

(2) Effect of temperature on ultimate tensile strength at temperature is shown in Figure 60. Effect of temperature on tensile yield strength is shown in Figure 61. Effect of temperature on compressive yield strength is shown in Figure 62. Effect of temperature on shear and on bearing properties are shown in Figures 63, 64, and 65.

(3) Stress-strain curves in tension and compression (typical curves) are shown in Figures 66 and 67.

(4) S/N diagrams showing typical room temperature and elevated temperature characteristics of smooth and of notched specimens are shown in Figures 68, 69, 70, and 71, modified Goodman diagrams in Figures 72 and 73.

(5) Discussion of fracture toughness and of delayed failure characteristics is included in Section IV.

(6) Discussion of creep characteristics is included in Section IV.

Ti-6Al-6V-2Sn TENTATIVE DESIGN PROPERTIES

(1) Tentative room temperature design mechanical properties are summarized in Table XVI.

(2) Effect of temperature on ultimate tensile strength at temperature is shown in Figure 74. Effect of temperature on tensile yield strength is shown in Figure 75. Effect of temperature on compressive yield strength is shown in Figure 76. Effect of temperature on shear and on bearing properties is shown in Figures 77, 78, and 79.

(3) Stress-strain curves in tension and compression (typical curves) are shown in Figures 80 and 81.

(4) S/N diagrams showing typical room temperature and elevated temperature characteristics of smooth and of notched specimens are shown in Figures 82, 83, 84 and 85, modified Goodman diagrams in Figures 86 and 87.

(5) Fracture toughness and delayed failure characteristics are discussed in Section IV.

(6) Creep characteristics are discussed in Section IV.

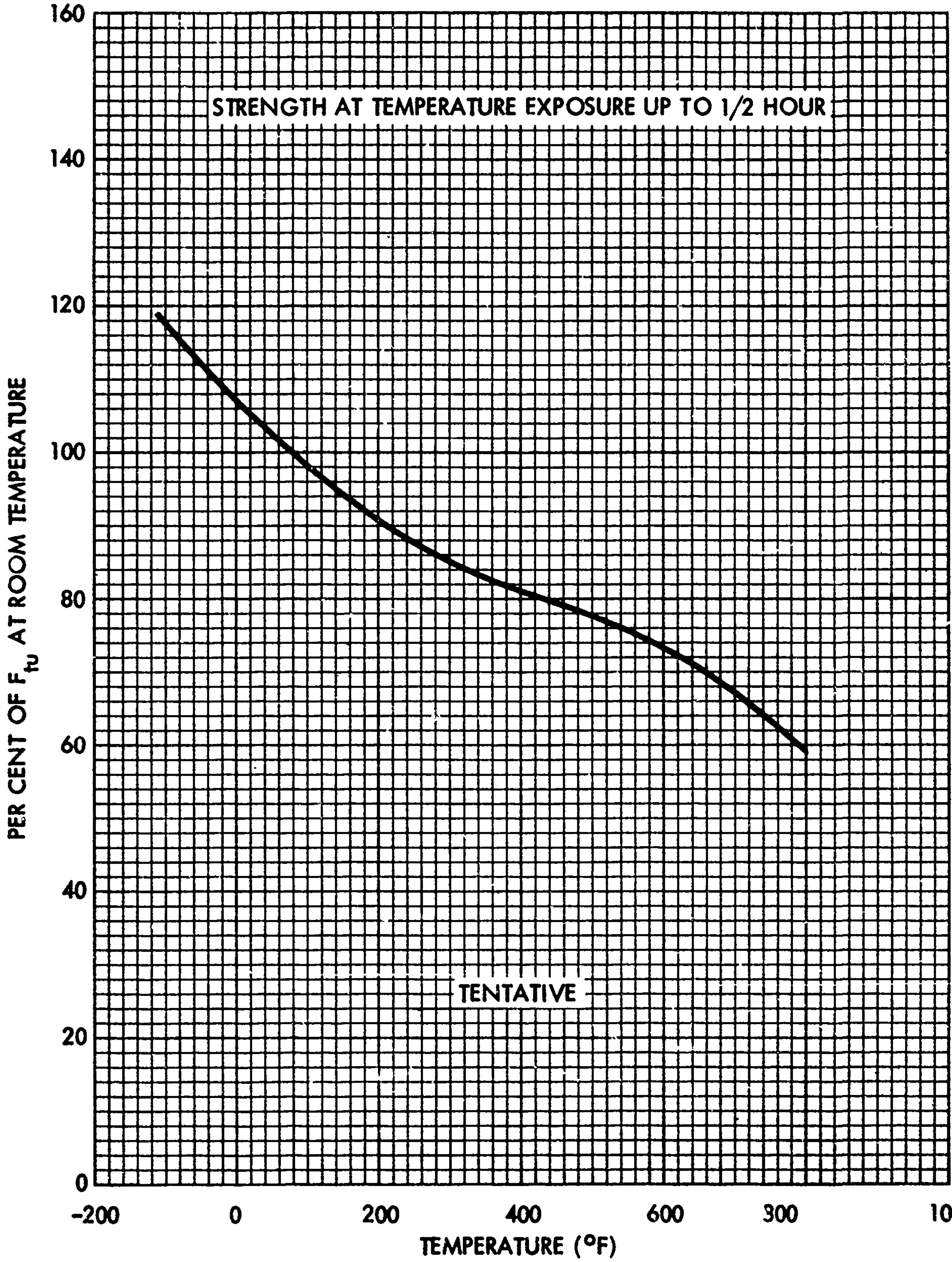


Figure 60. Effect of Temperature on the Ultimate Tensile Strength (F_{tu}) of Annealed Ti-8Al-1Mo-1V Extrusions

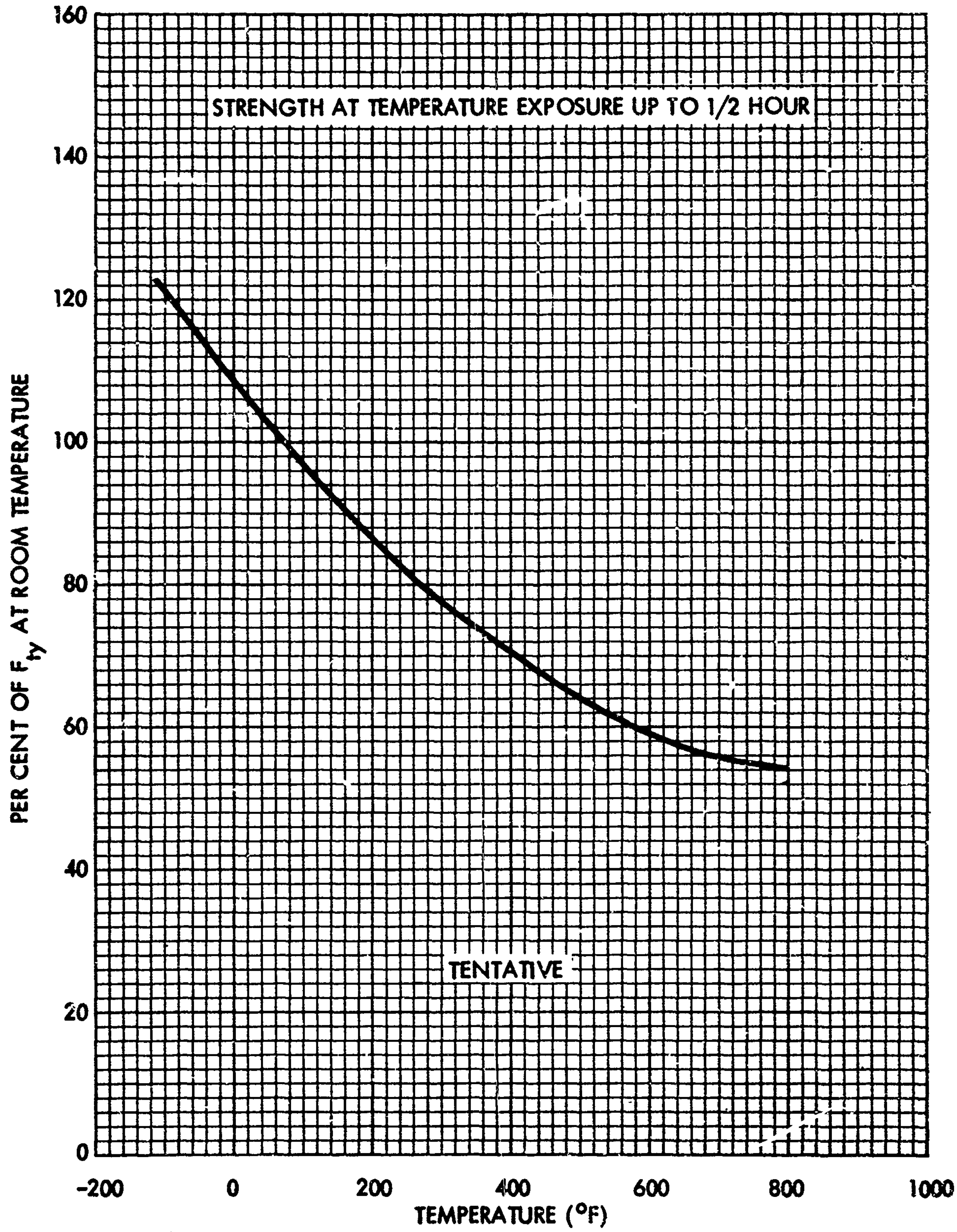


Figure 61. Effect of Temperature on the Tensile Yield Strength (F_{ty}) of Annealed Ti-8Al-1Mo-1V Extrusions

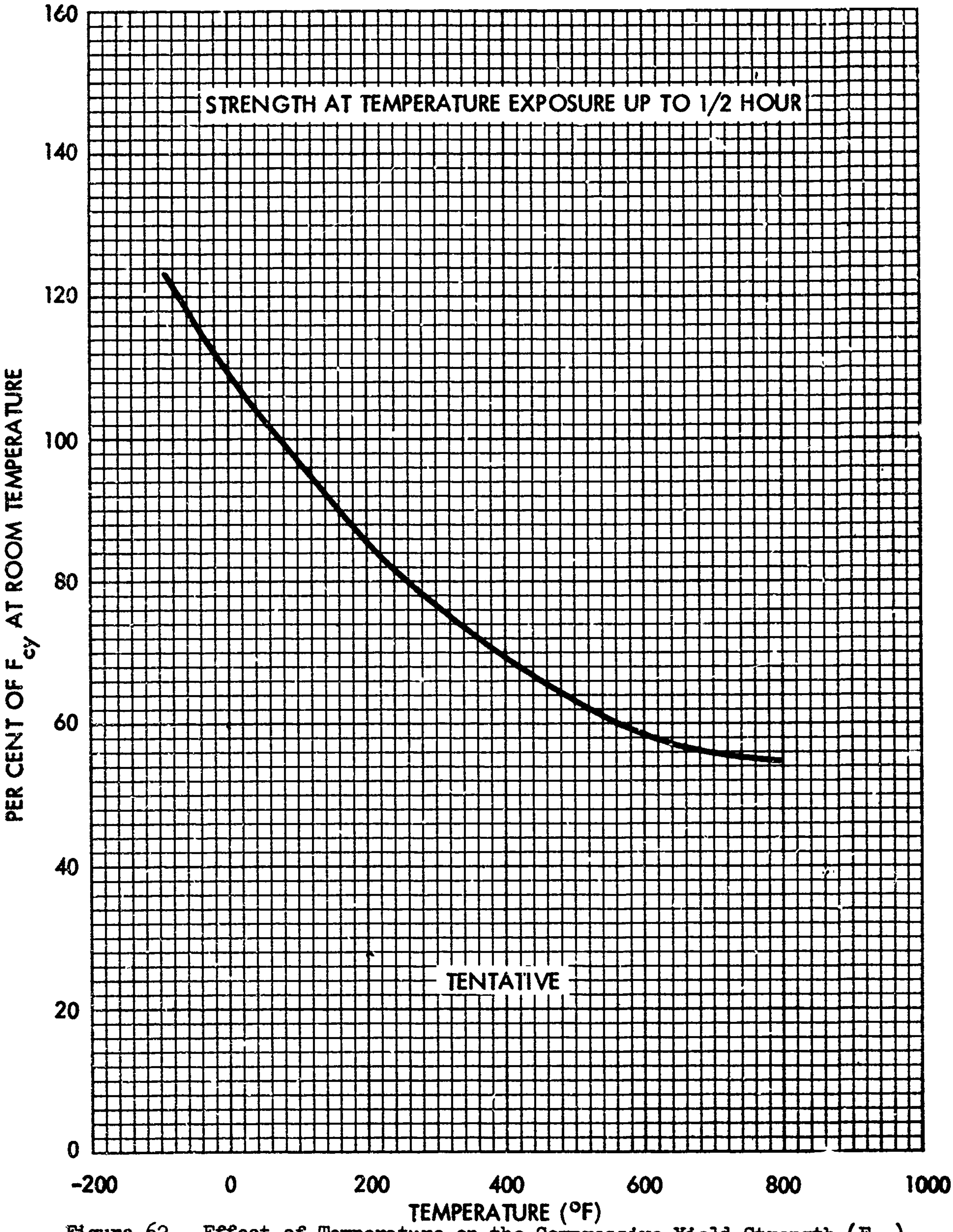


Figure 62. Effect of Temperature on the Compressive Yield Strength (F_{cy}) of Annealed Ti-8Al-1Mo-1V Extrusions

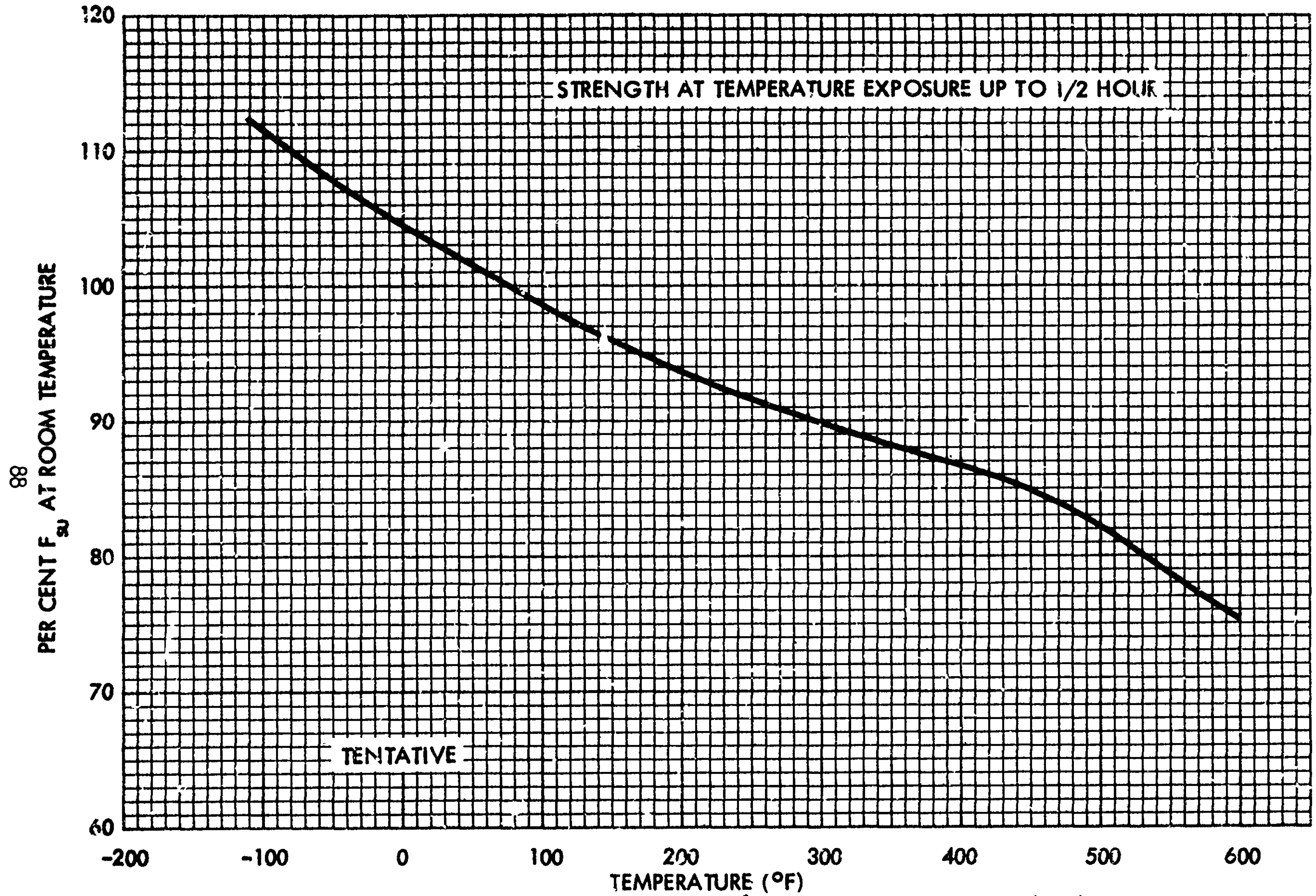


Figure 63. Effect of Temperature on the Ultimate Shear Strength (F_{su}) of Ti-8Al-1Mo-1V Extrusions

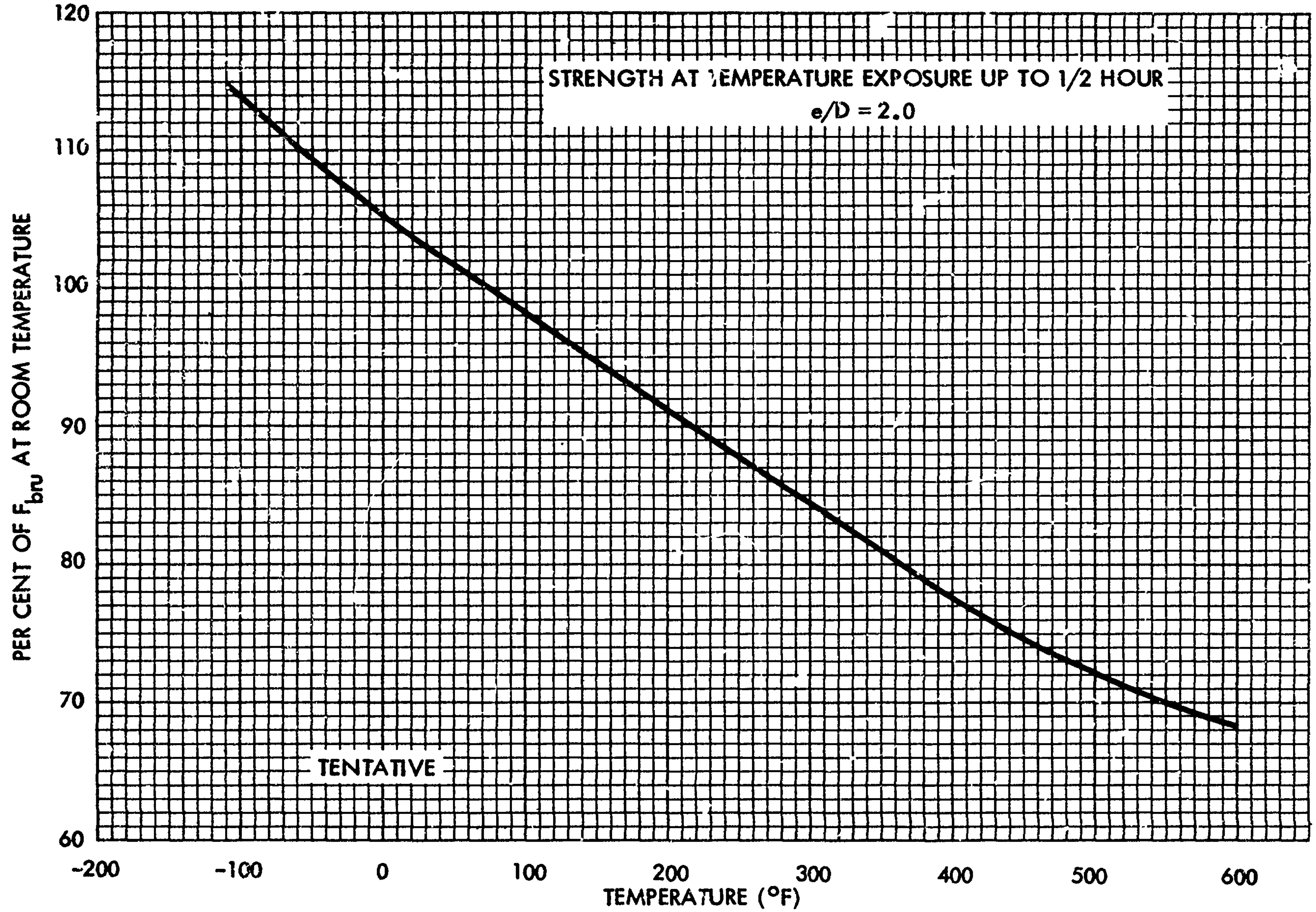


Figure 64. Effect of Temperature on the Ultimate Bearing Strength (F_{bru}) of Ti-8Al-1Mo-1V Extrusions

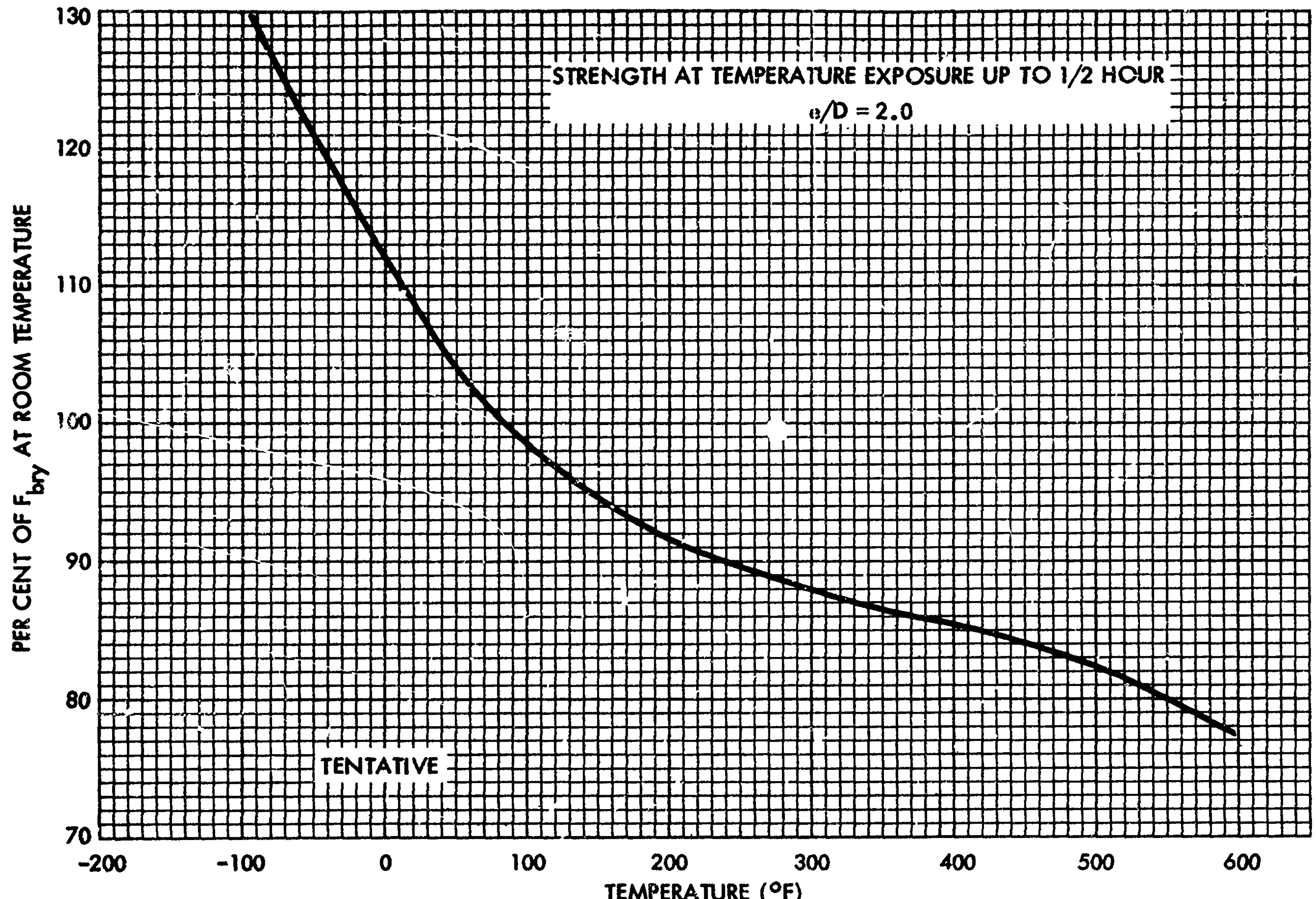


Figure 65. Effect of Temperature on the Bearing Yield Strength (F_{bry}) of Ti-8Al-1Mo-1V Extrusions

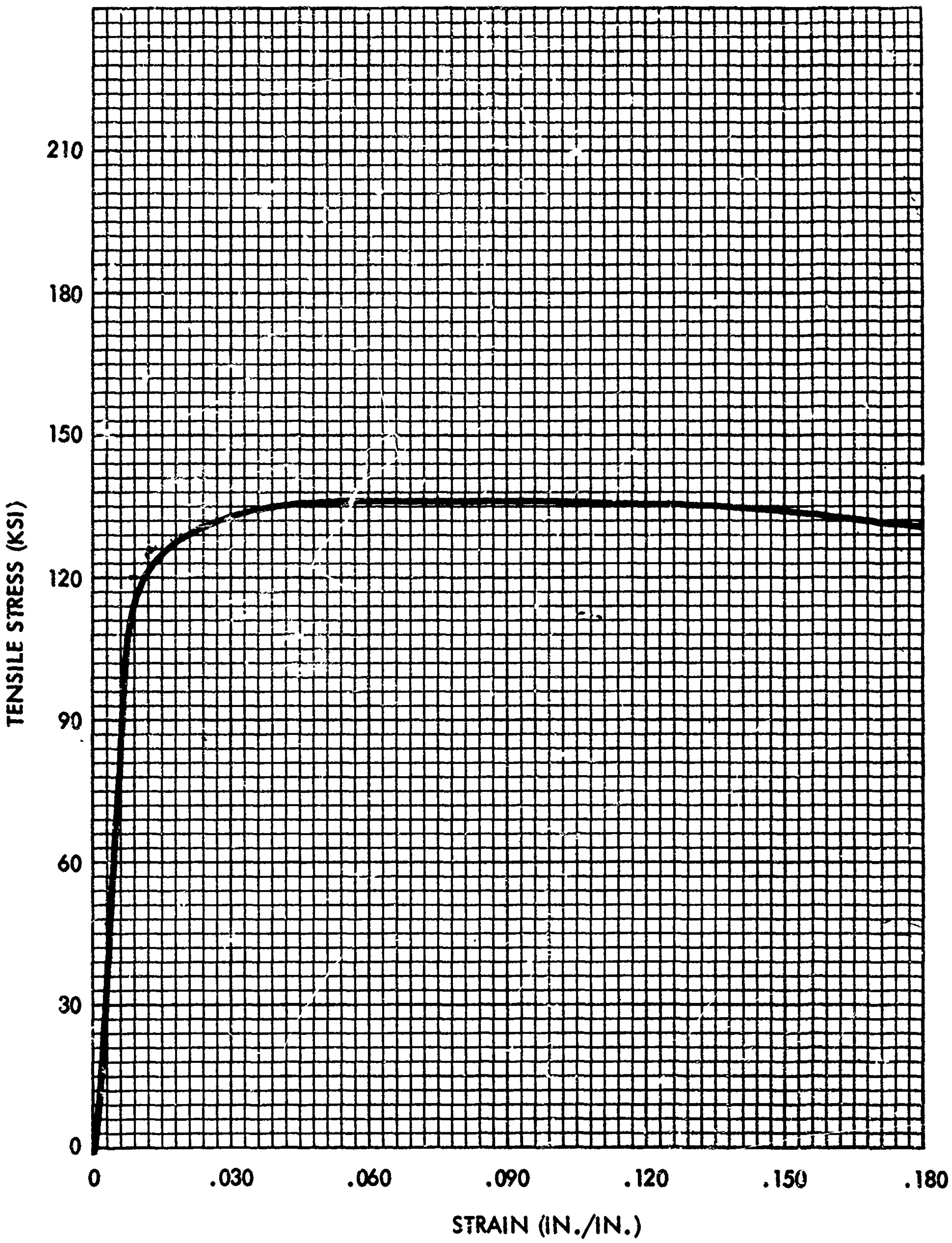


Figure 66. Typical Tensile Stress--Strain Curve Ti-8Al-1Mo-1V Extrusion at Room Temperature

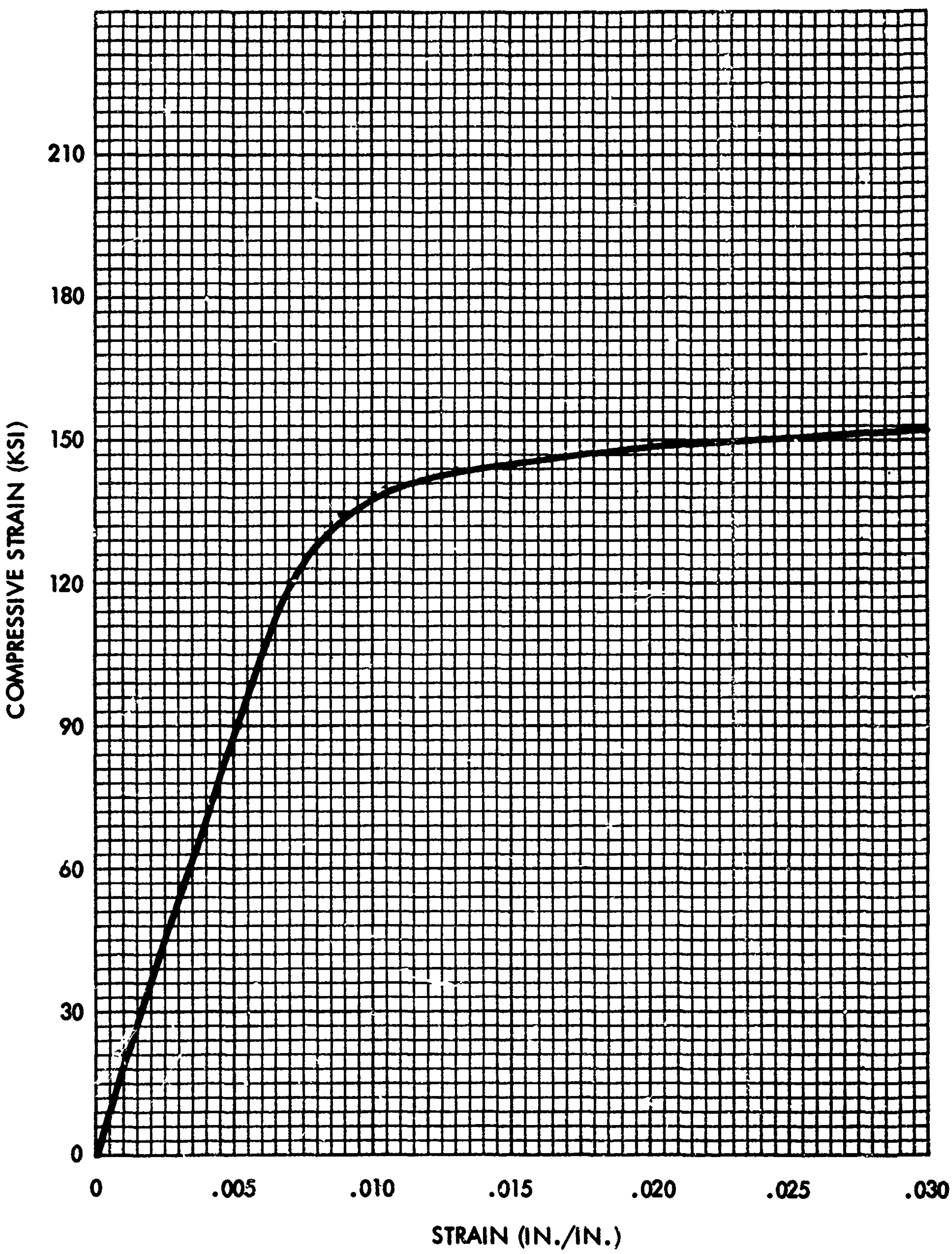


Figure 67. Typical Compressive Stress--Strain Curve
Ti-8Al-1Mo-1V Extrusions at Room Temperature

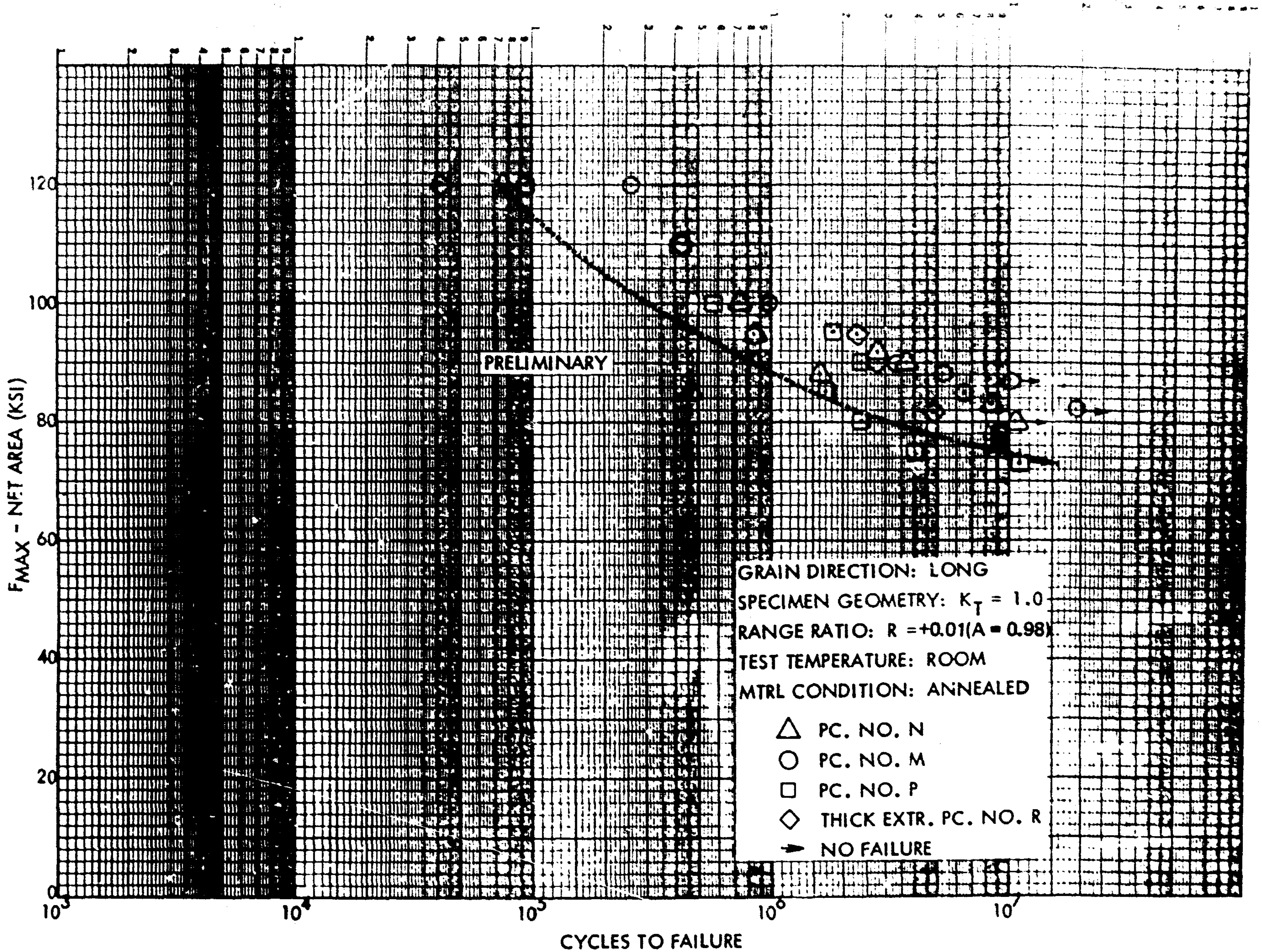


Figure 68. Typical S/N Fatigue Curve for K_T = 1.0, Ti-8Al-1Mo-1V Extrusions at Room Temperature

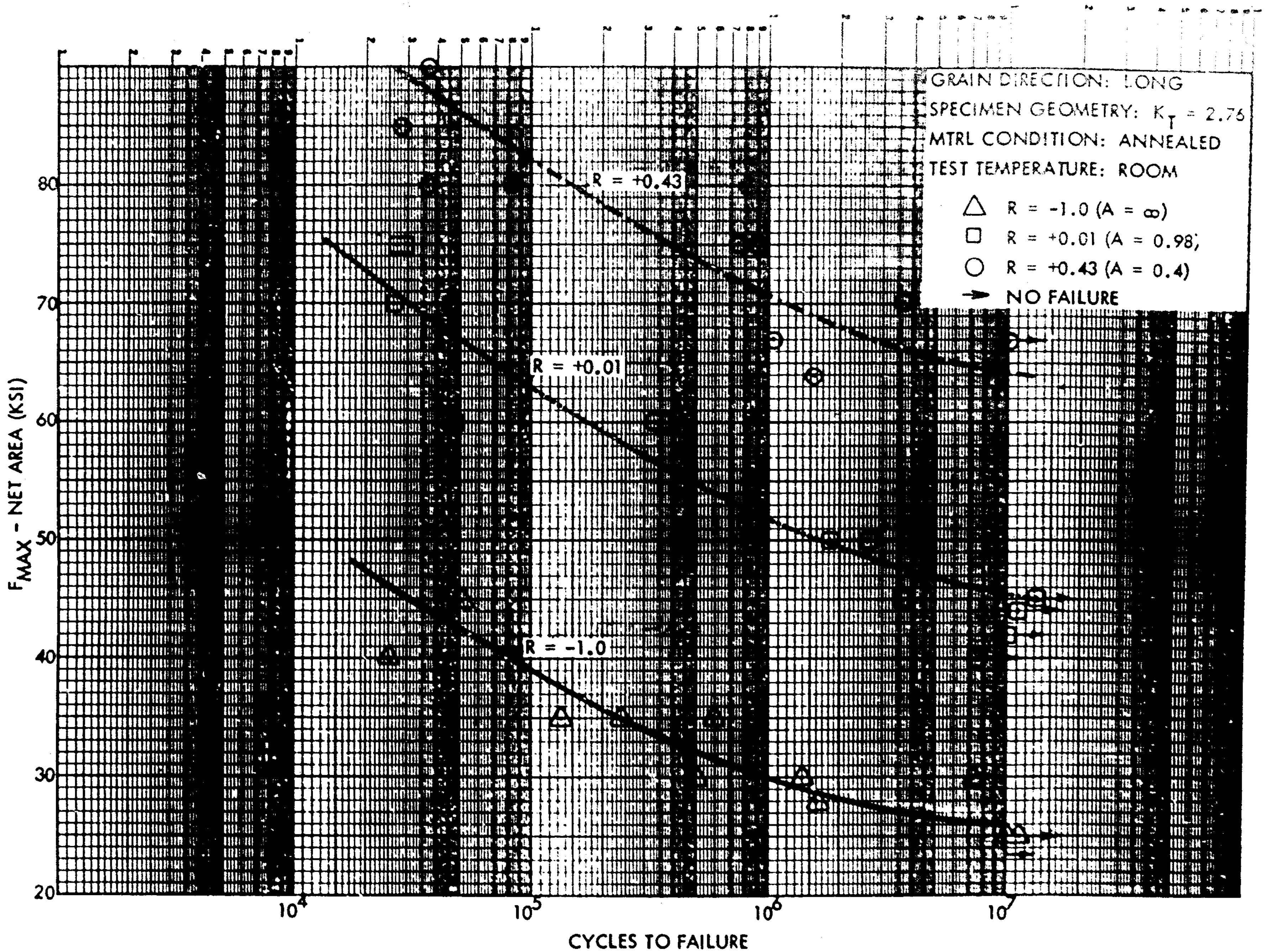


Figure 69. Typical S/N Fatigue Curves for $K_T = 2.76$ ($A = \infty$, $A = 0.98$, $A = 0.4$) Ti-8Al-1Mo-1V Extrusions at Room Temperature

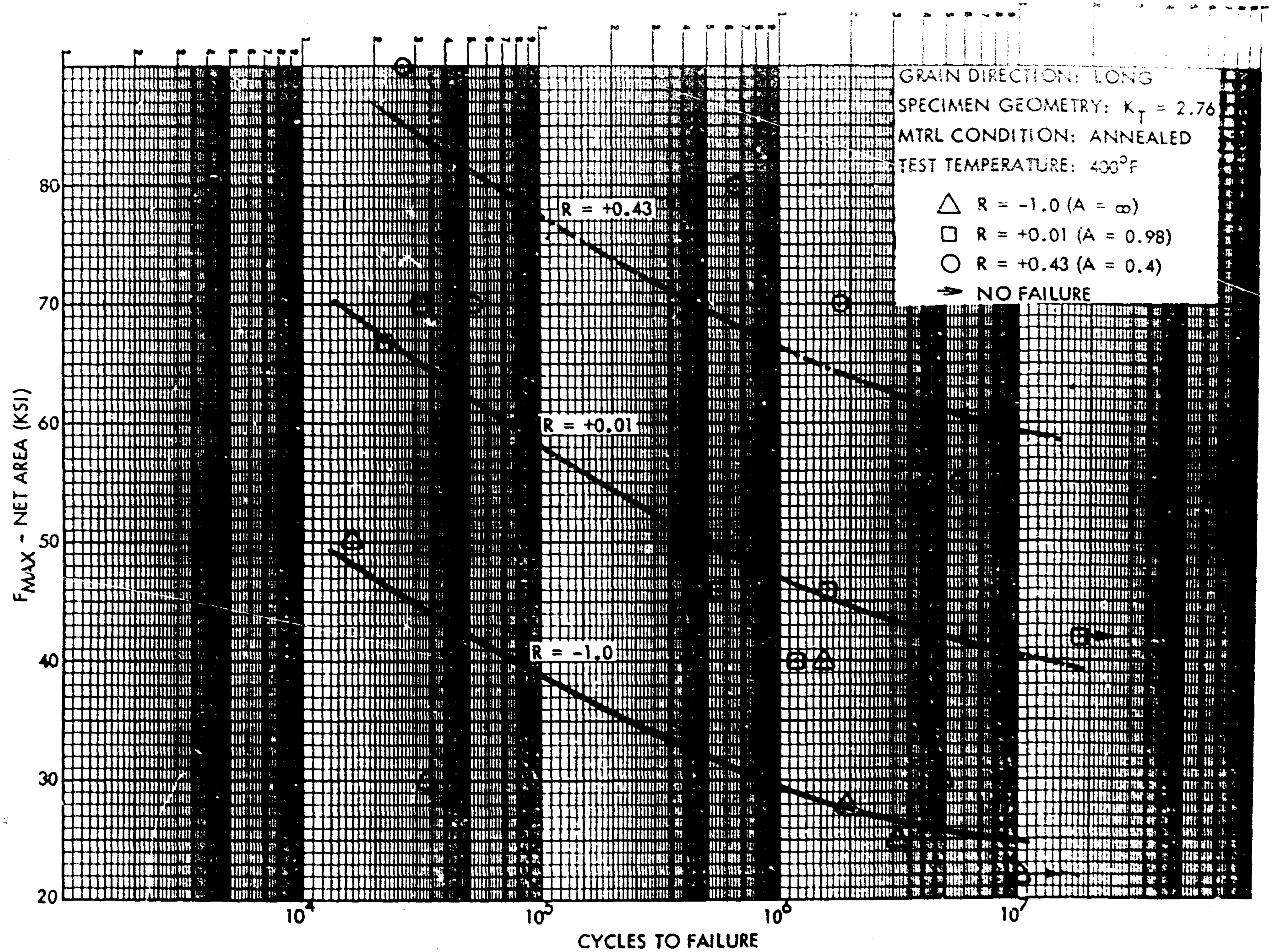


Figure 70. Typical S/N Fatigue Curves for K_T = 2.76 (A = ∞, A - 0.98, A = 0.4) Ti-8Al-1Mo-1V Extrusions at 400F

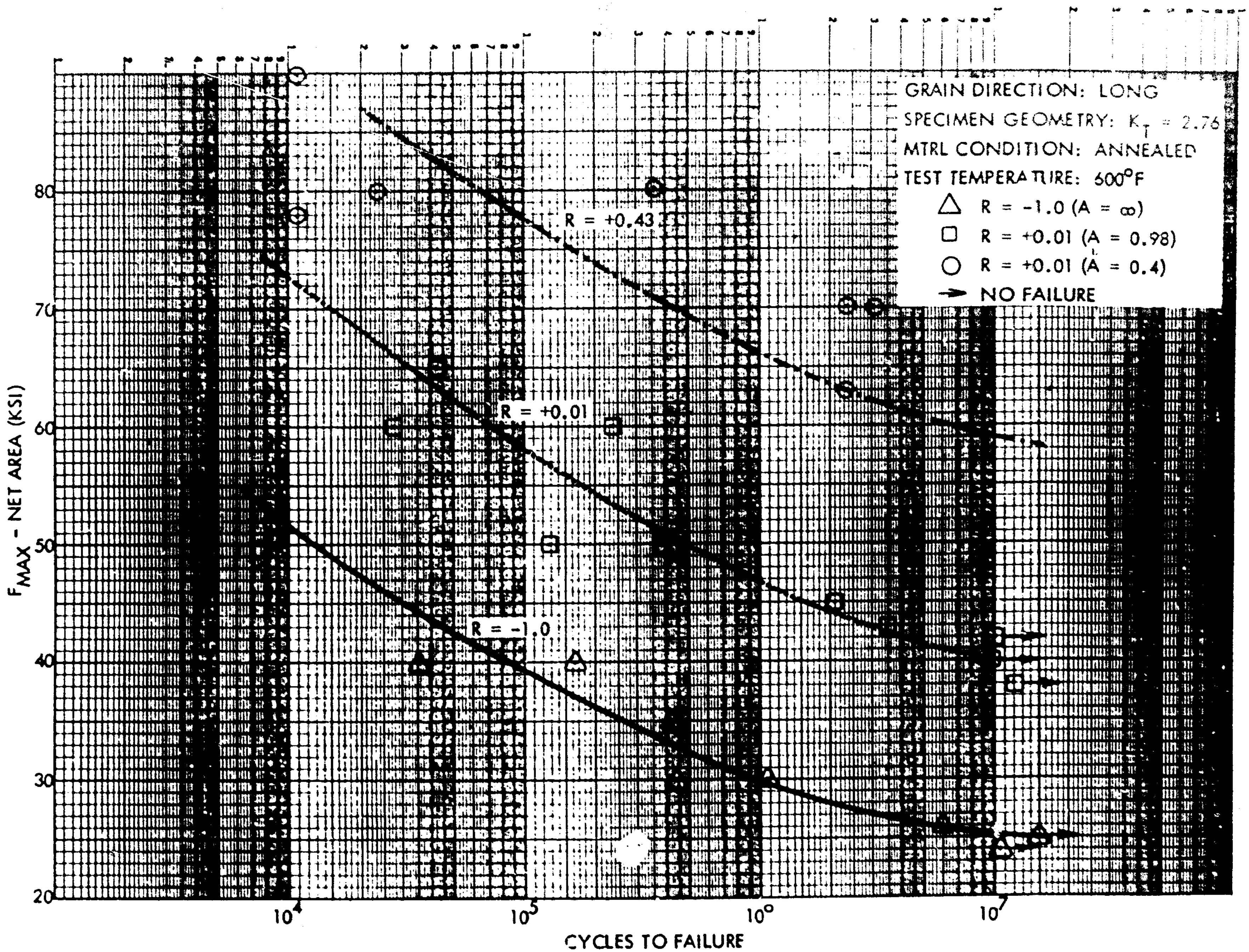


Figure 71. Typical S/N Fatigue Curves for K_T = 2.76 (A = ∞, A - 0.98, A = 0.4) Ti-8Al-1Mo-1V Extrusions at 600F

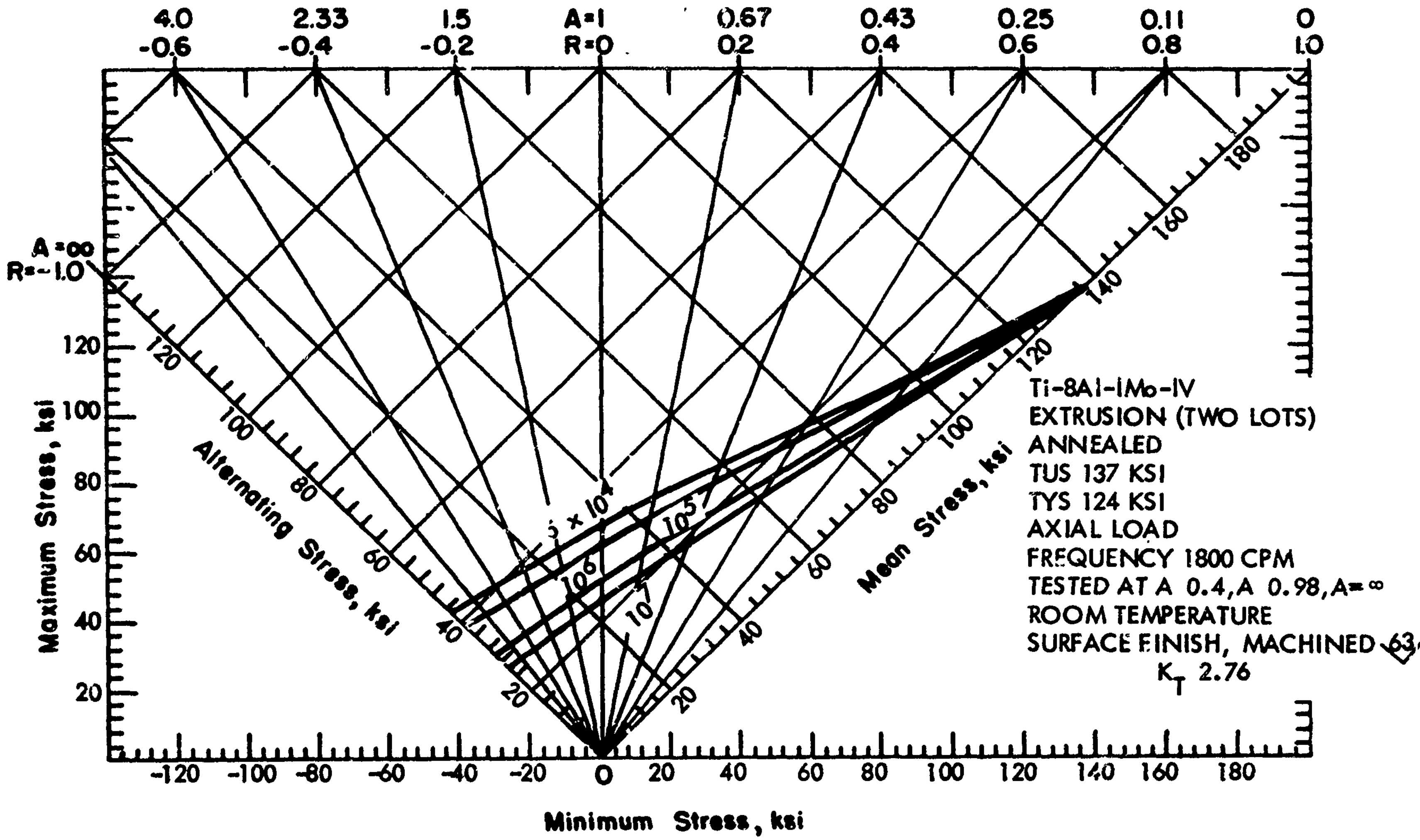


Figure 72. Constant-life Fatigue Diagram for Notched Ti-8Al-1Mo-1V Annealed Extrusions at Room Temperature

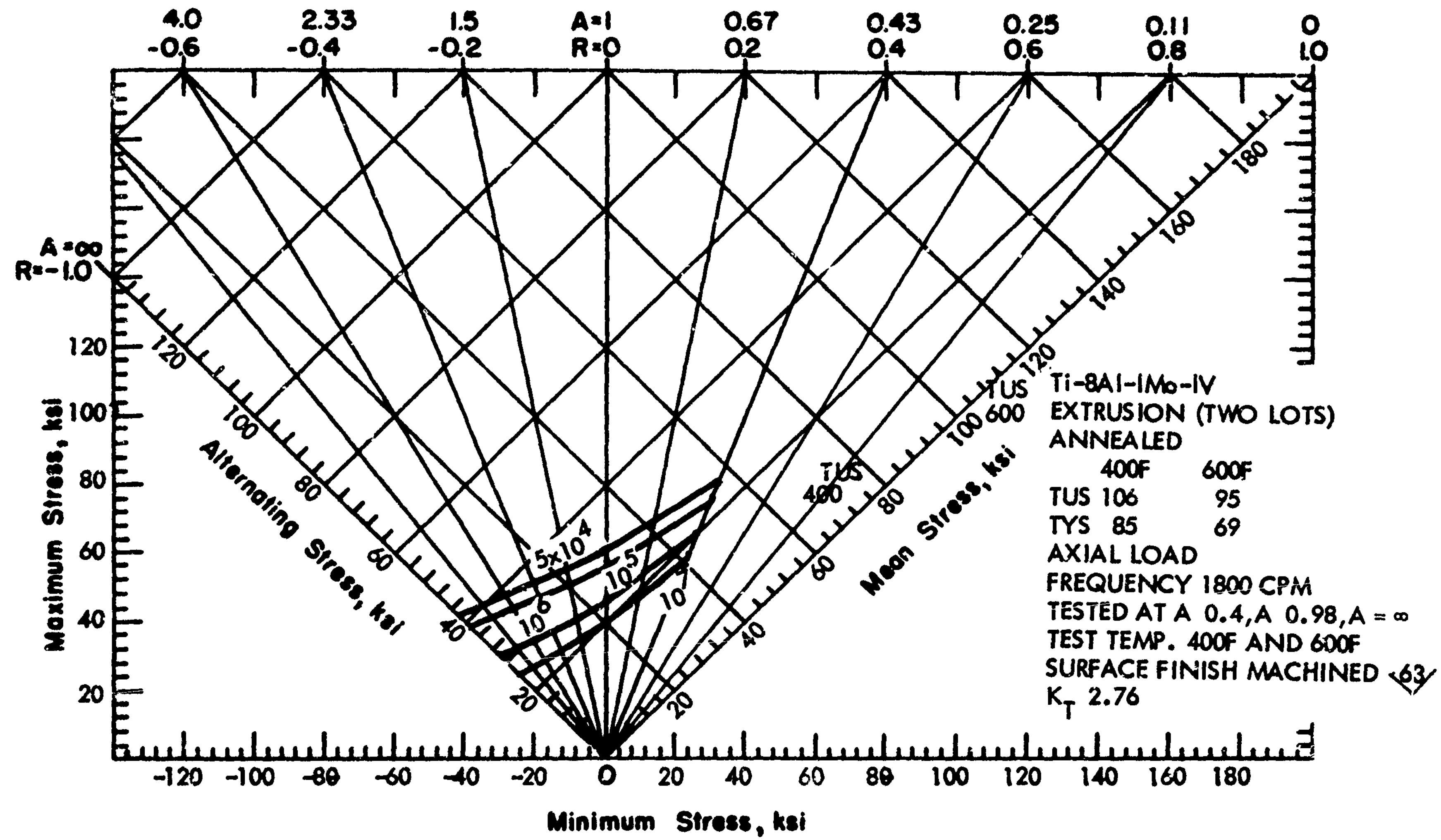


Figure 73. Constant-life Fatigue Diagram for Notched Ti-8Al-1Mo-1V Annealed Extrusions at 400F and 600F

Table XVI Tentative Design Mechanical and Physical Properties of Ti-6Al-6V-2Sn Titanium Alloy (Extrusions)

Alloy	Ti-6Al-6V-2Sn
Form	Extruded Shapes, Rod and Bar
Condition	Annealed
Thickness or diameter, in.	
Basis	S
Mechanical properties:	
F_{tu}, ksi	
L	150
LT	150
F_{ty}, ksi	
L	135
LT	135
F_{cy}, ksi	(Typical values shown in Table VI)
L	
LT	
F_{su}, ksi	(Typical values shown in Table XI)
F_{bru}, ksi:	
(e/D = 1.5)	(Typical values shown in Table IX)
(e/D = 2.0)	
F_{bry}, ksi:	
(e/D = 1.5)	(Typical values shown in Table X)
(e/D = 2.0)	
e, per cent:	
In 2 in.	10
In 4 D	10
E, 10^6 psi	16.1
E_c, 10^6 psi	
G, 10^6 psi	
μ	
Physical properties:	
ω, lb/in.^{3}	0.164
C, Btu/(lb)(F)	
K, Btu/[(hr)(ft^2)(F)/ft]	
α, 10^{-6} in./in./F	

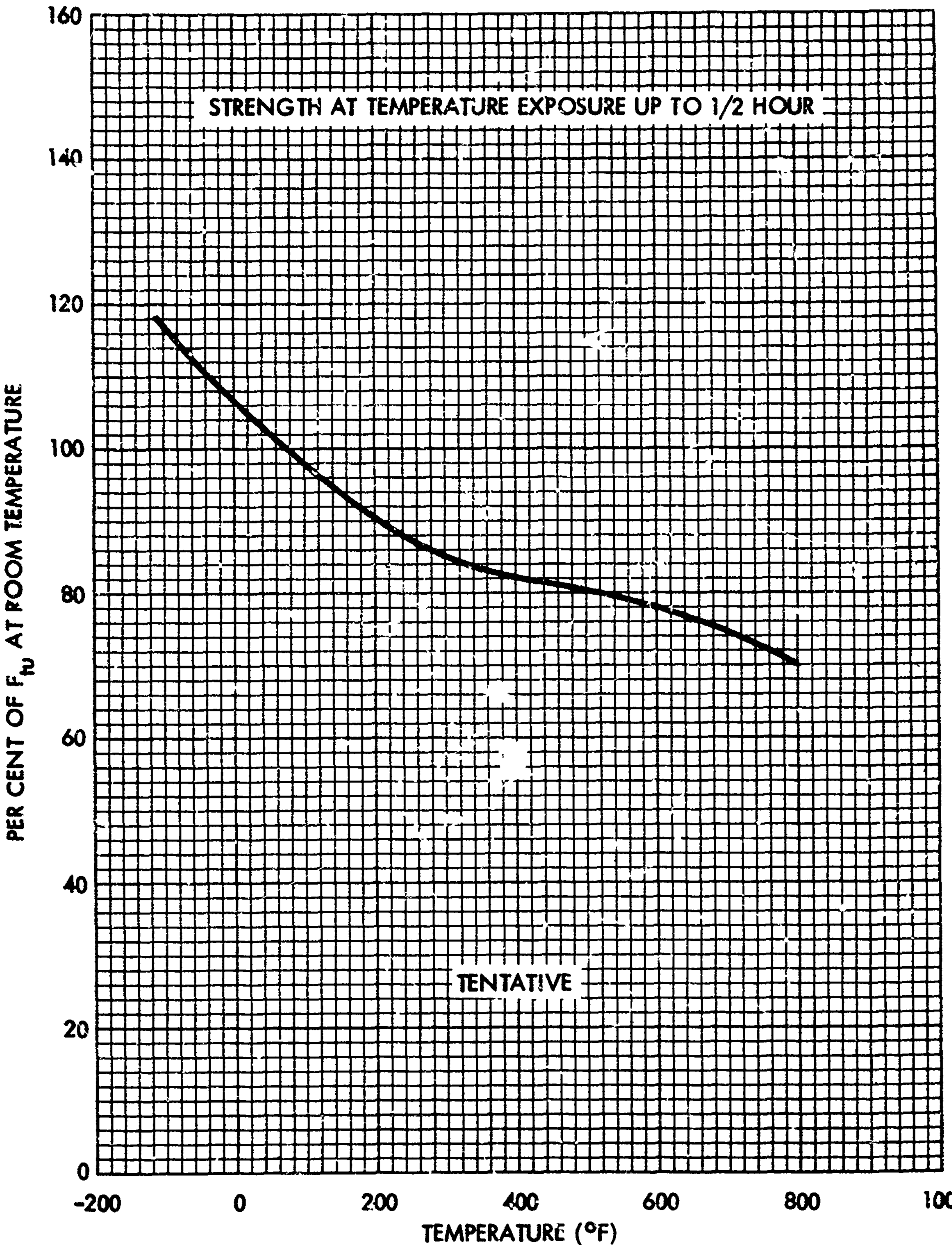


Figure 74. Effect of Temperature on the Ultimate Tensile Strength (F_{tu}) of Annealed Ti-6Al-6V-2Sn Extrusions

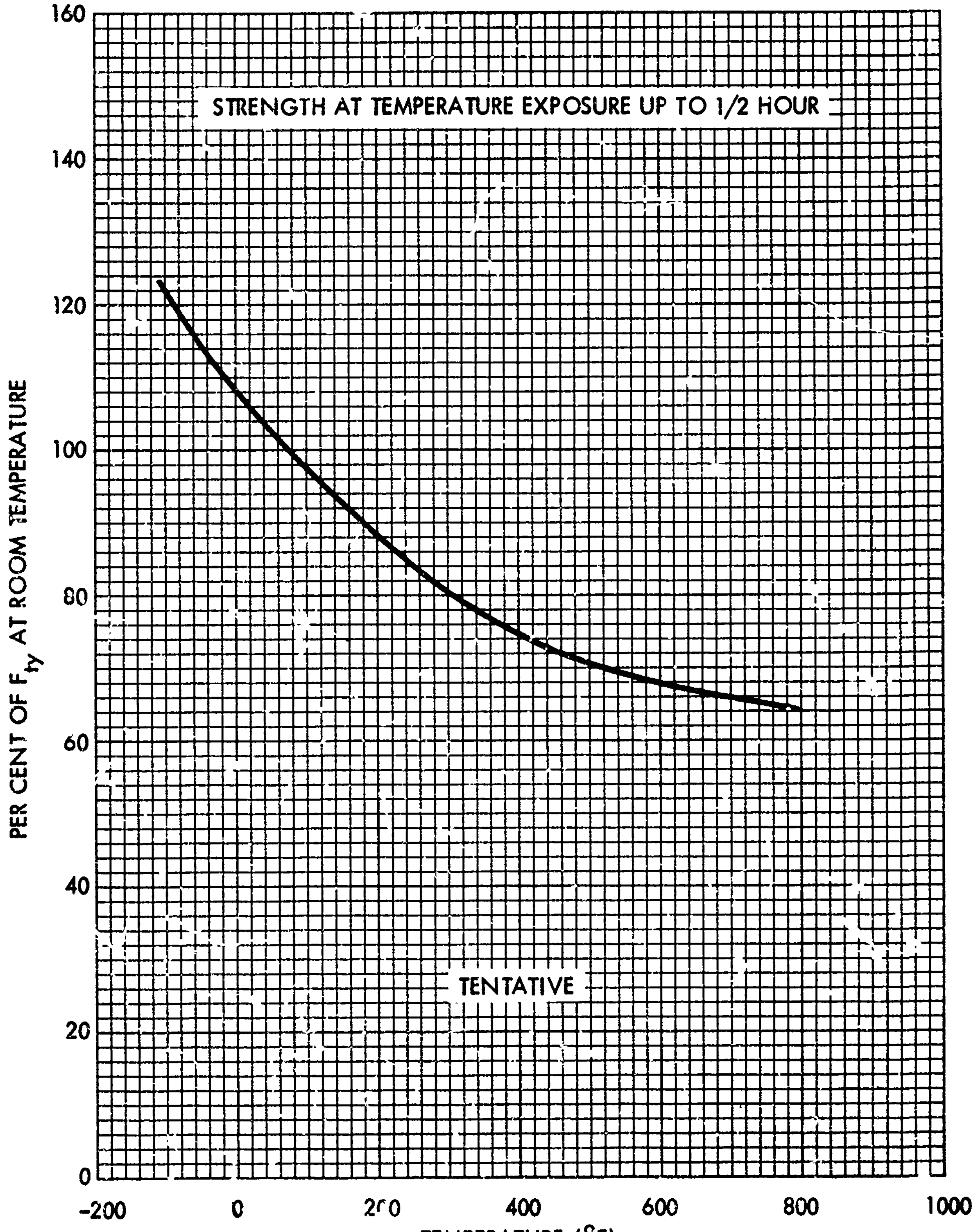


Figure 75. Effect of Temperature on the Tensile Yield Strength (F_{cy}) of Annealed Ti-6Al-6V-2Sn Extrusions

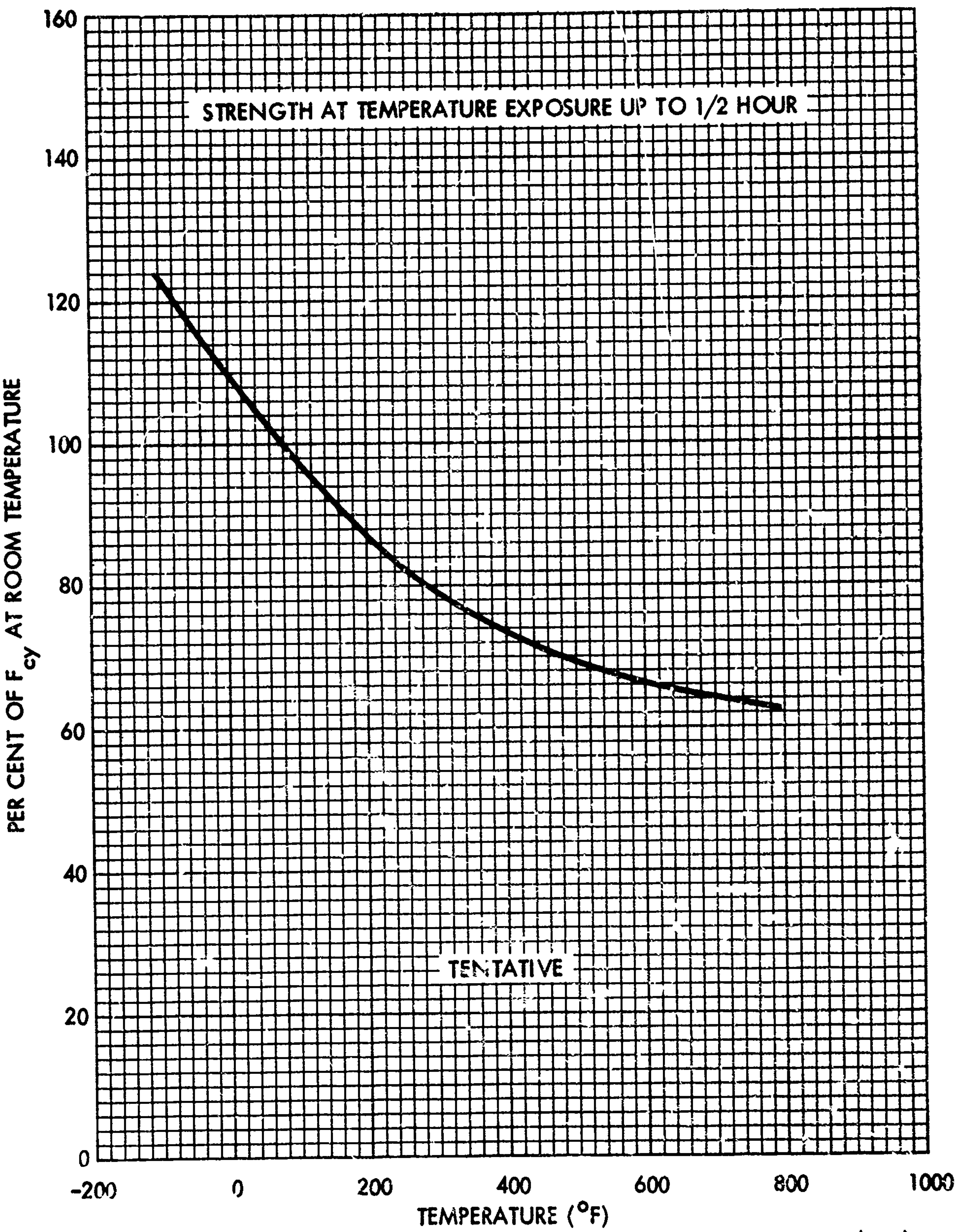


Figure 76. Effect of Temperature on the Compressive Yield Strength (F_{cy}) of Annealed Ti-6Al-6V-2Sn Extrusion

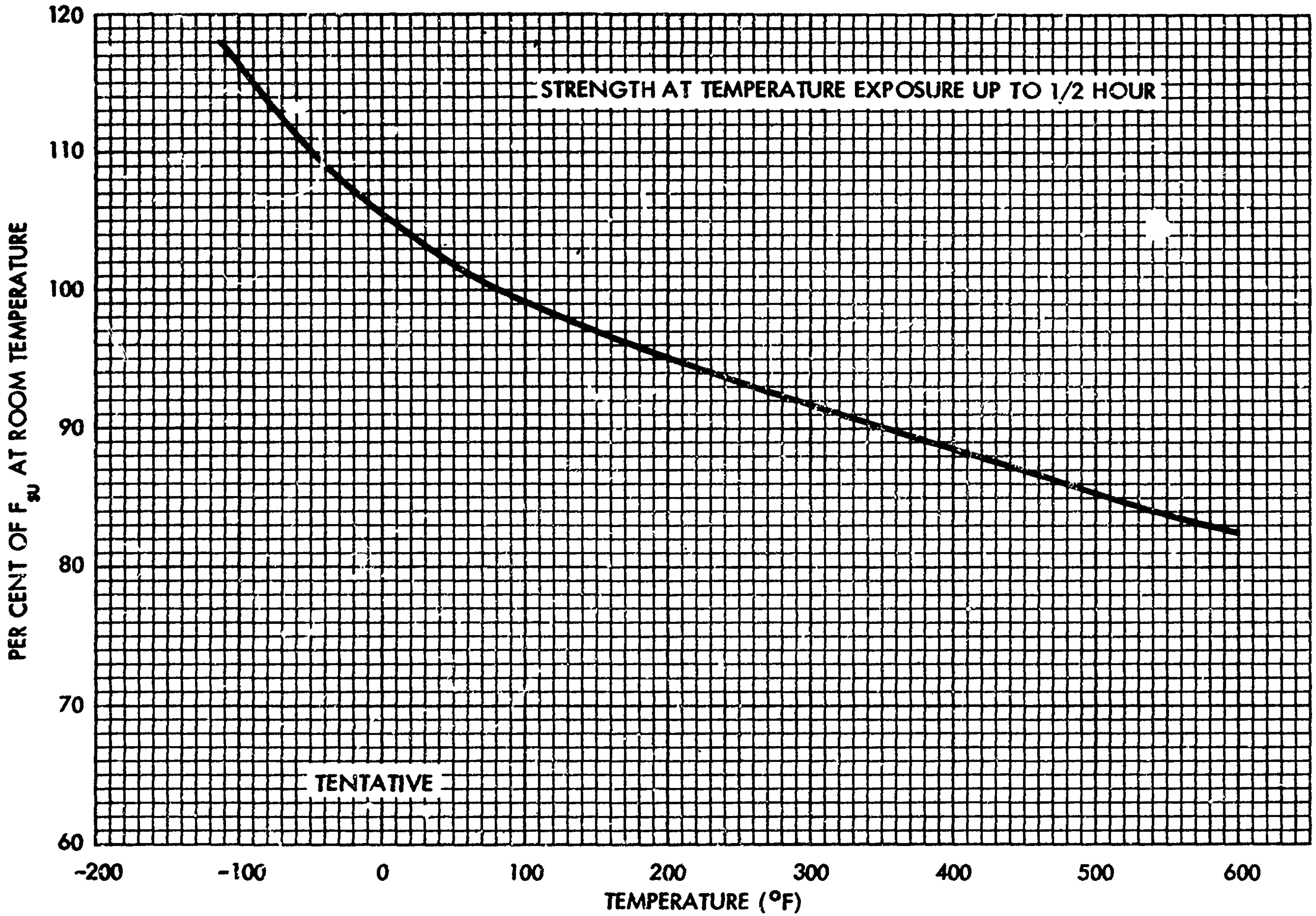


Figure 77. Effect of Temperature on the Ultimate Shear Strength (F_{su}) of Ti-6Al-6V-2Sn Extrusions

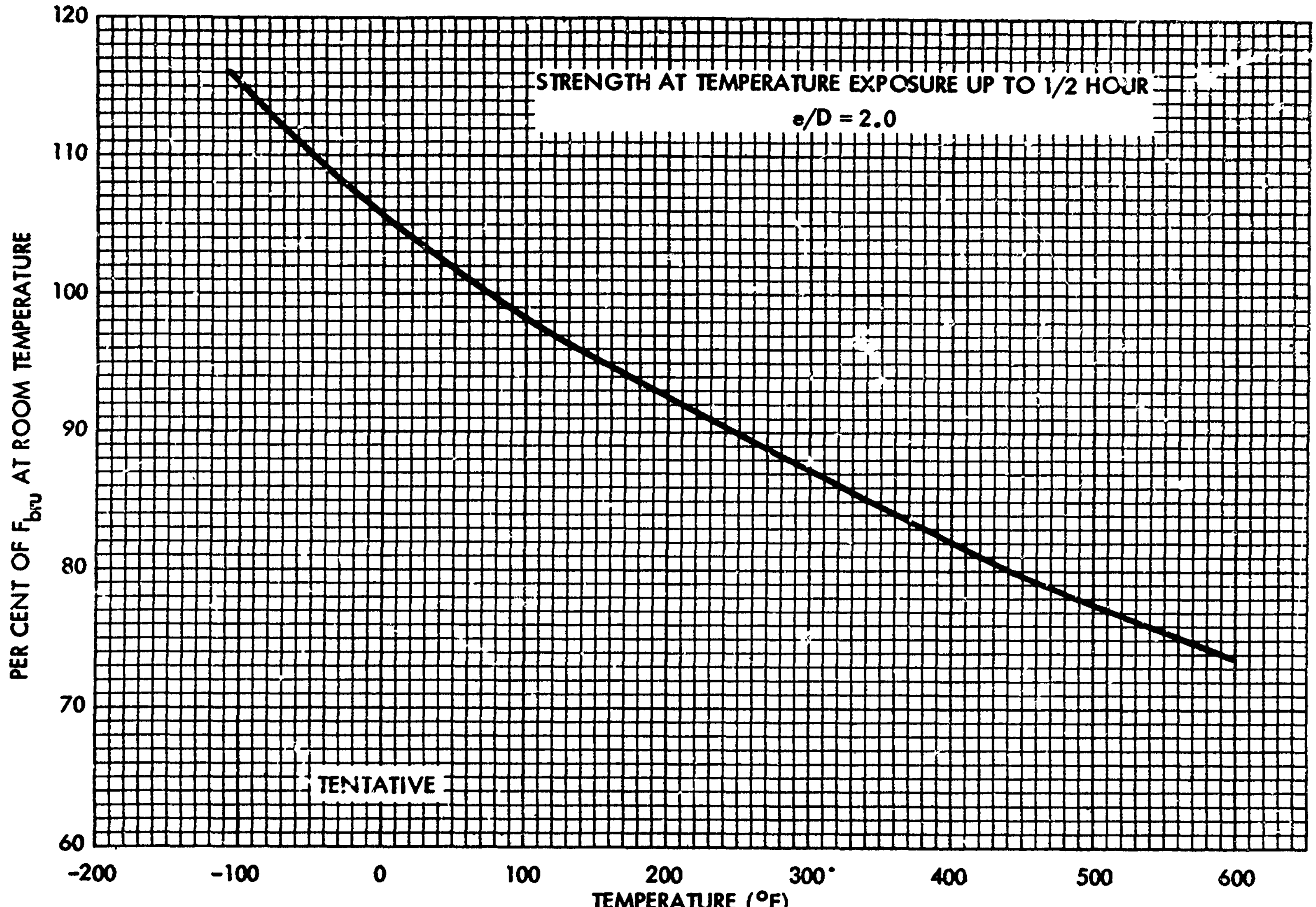


Figure 78. Effect of Temperature on the Ultimate Bearing Strength (F_{bru}) of Ti-6Al-6V-2Sn Extrusions

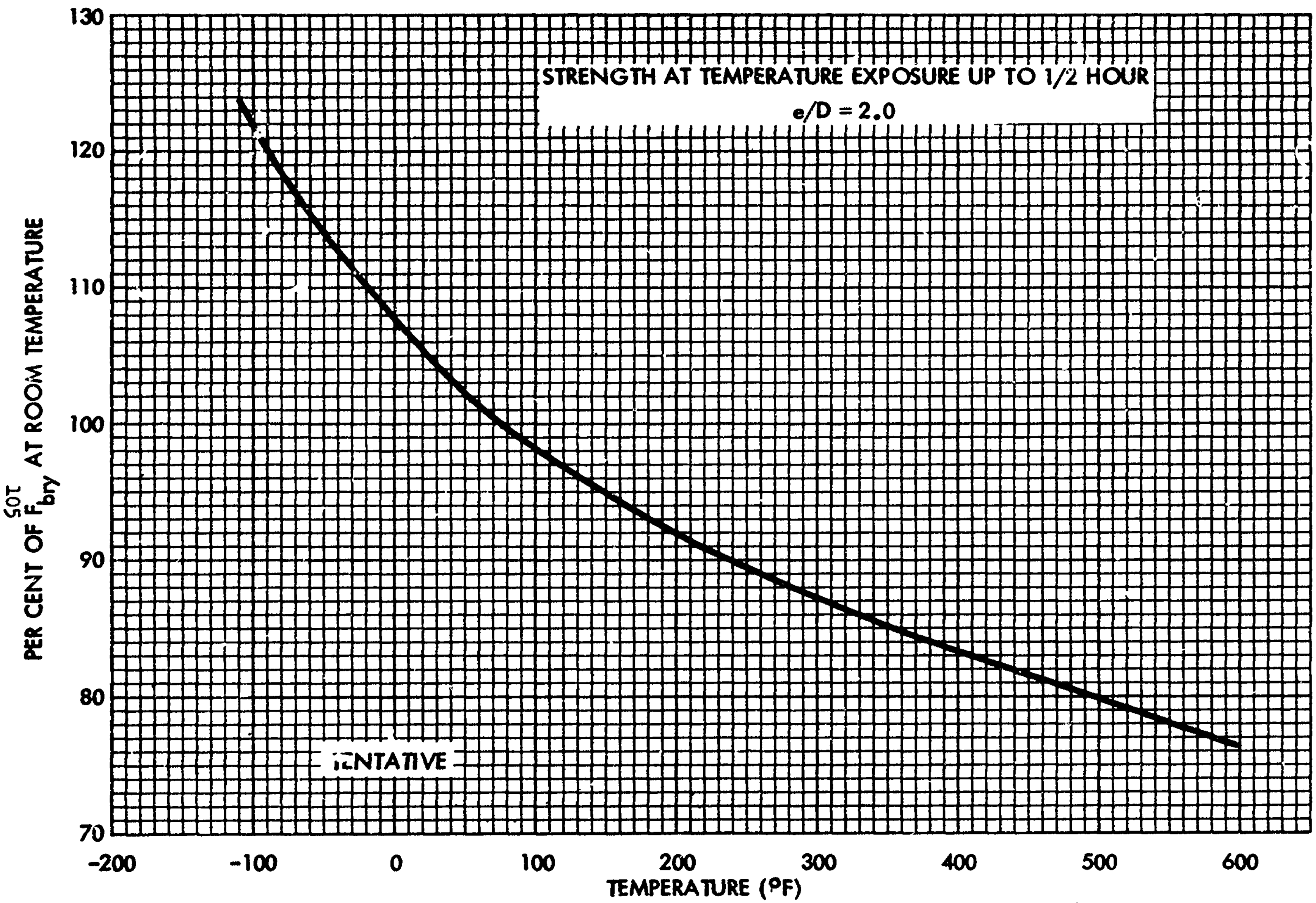


Figure 79. Effect of Temperature on the Bearing Yield Strength (F_{bry}) of Ti-6Al-6V-2Sn Extrusions

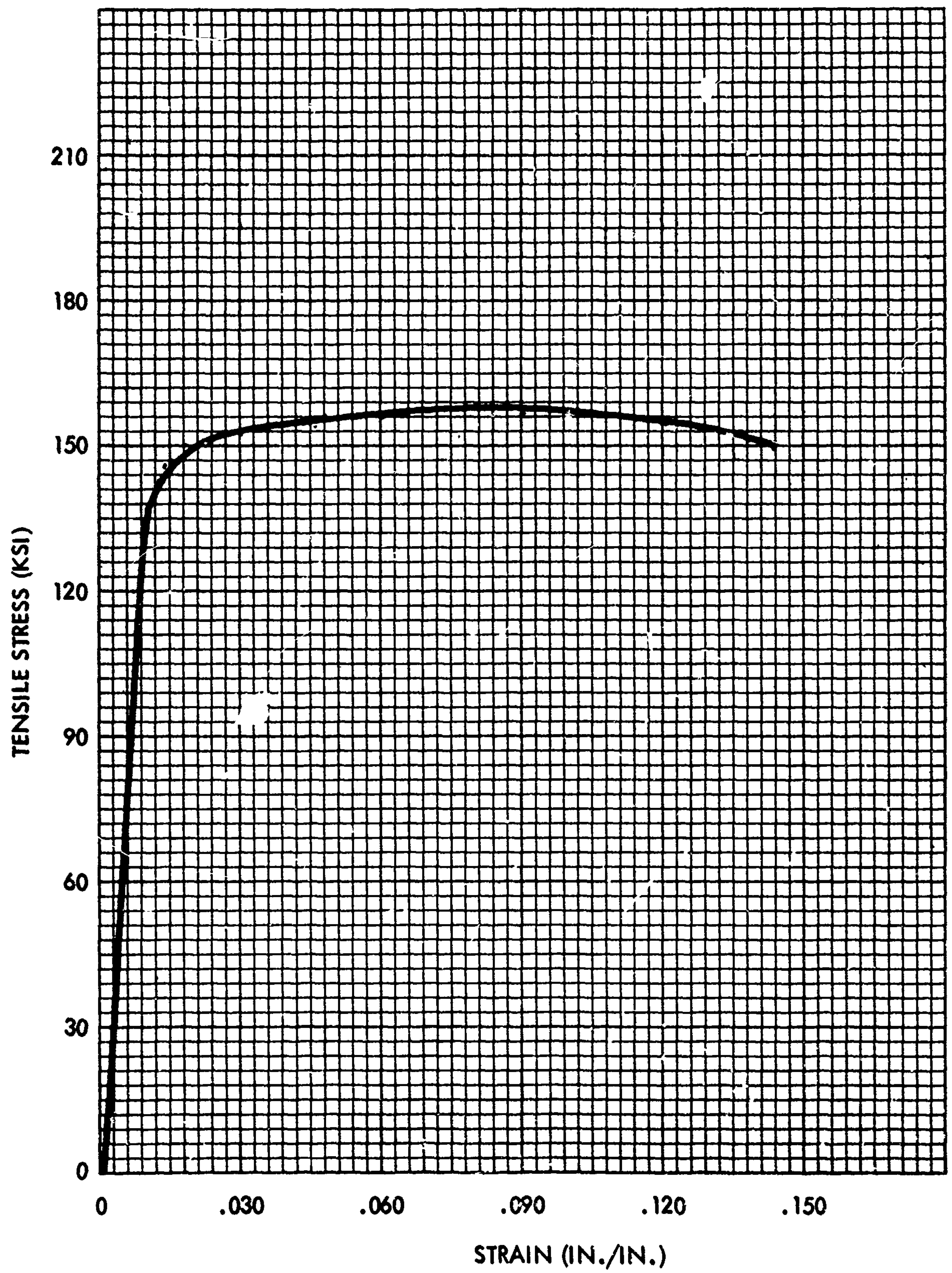


Figure 80. Typical Tensile Stress-Strain Curve
Ti-6Al-6V-2Sn Extrusions at Room Temperature

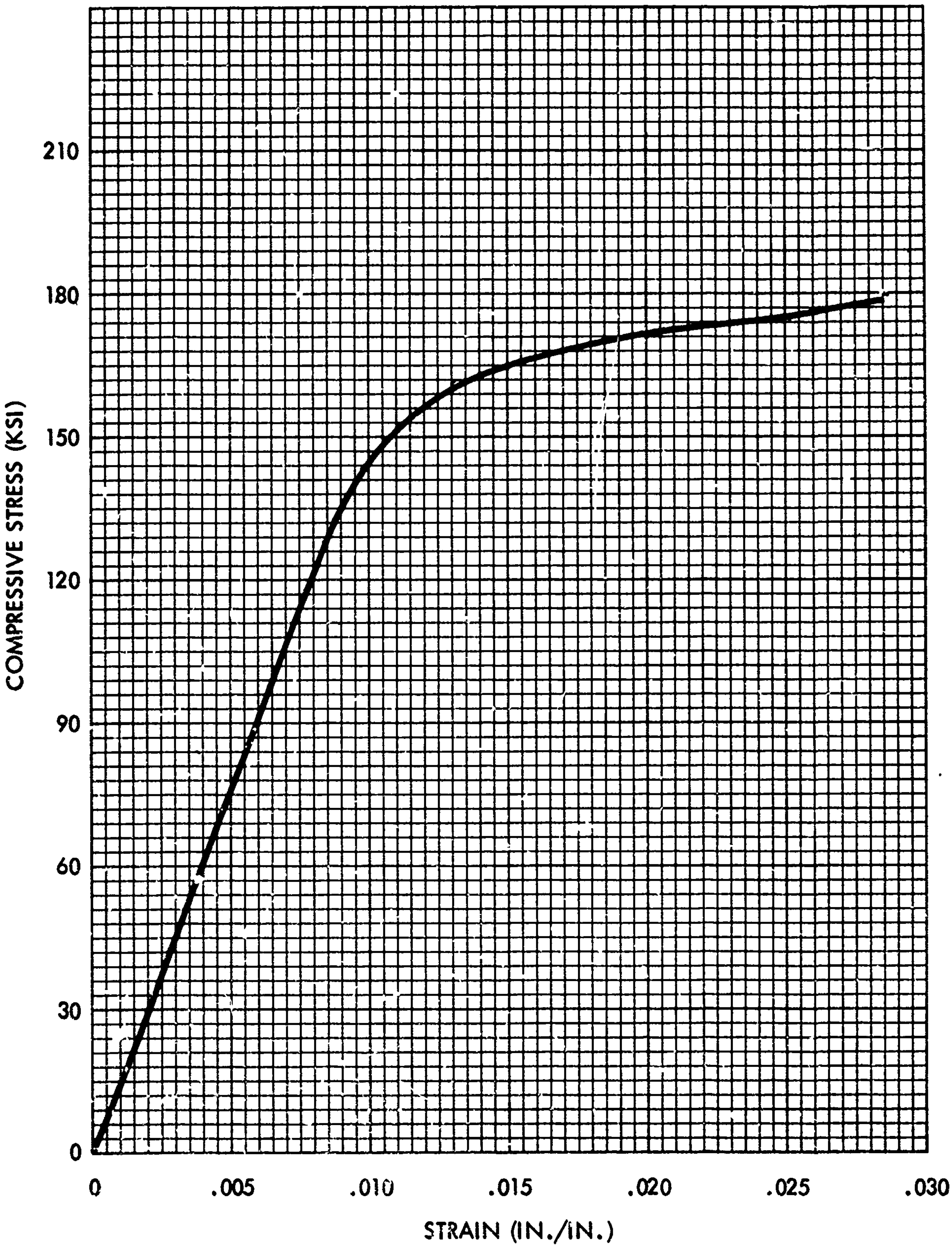


Figure 81. Typical Compressive Stress—Strain Curve
Ti-6Al-6V-2Sn Extrusions at Room Temperature

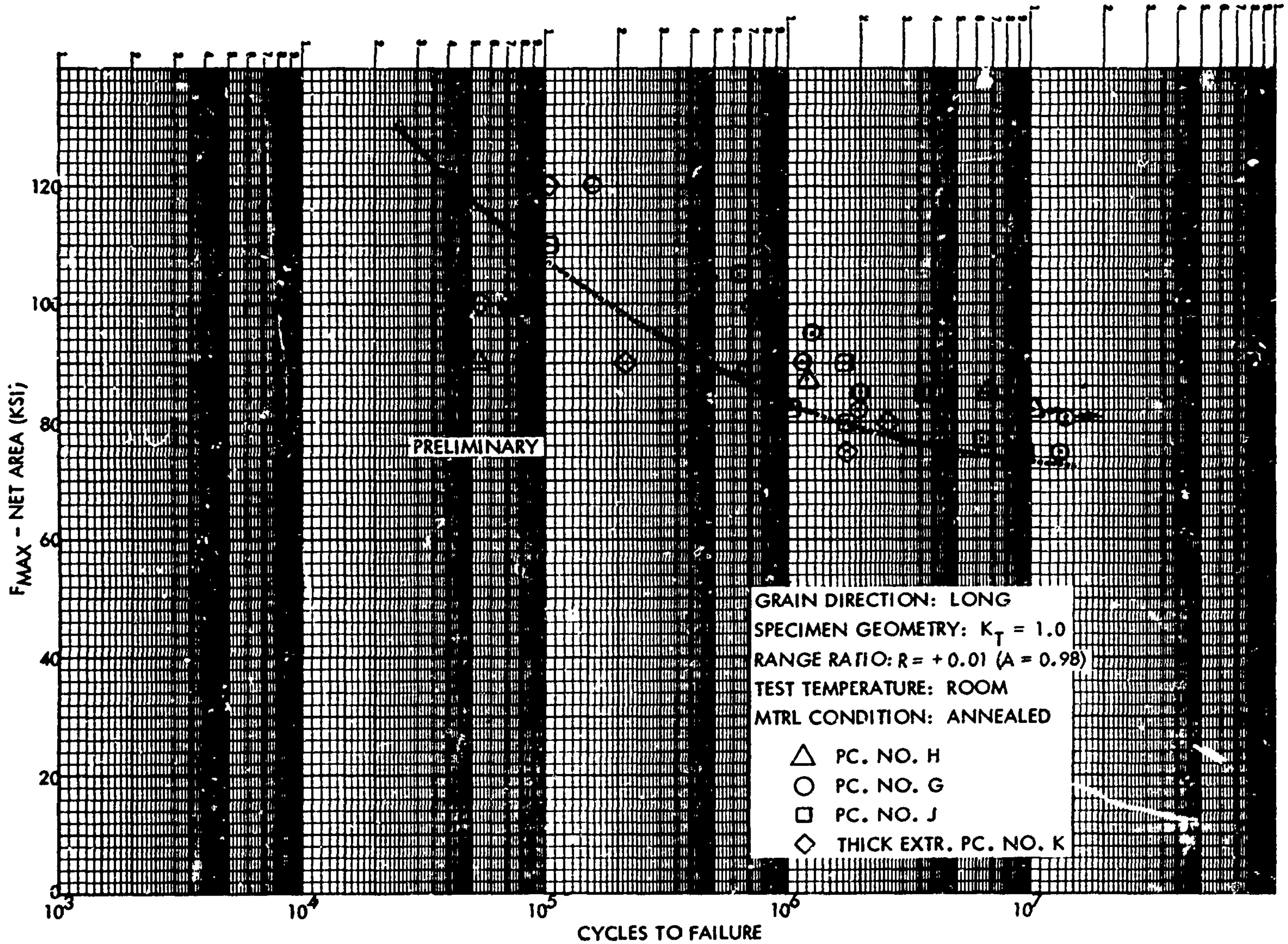


Figure 82. Typical S/N Fatigue Curve for K_T = 1.0, Ti-6Al-6V-2Sn Extrusions at Room Temperature

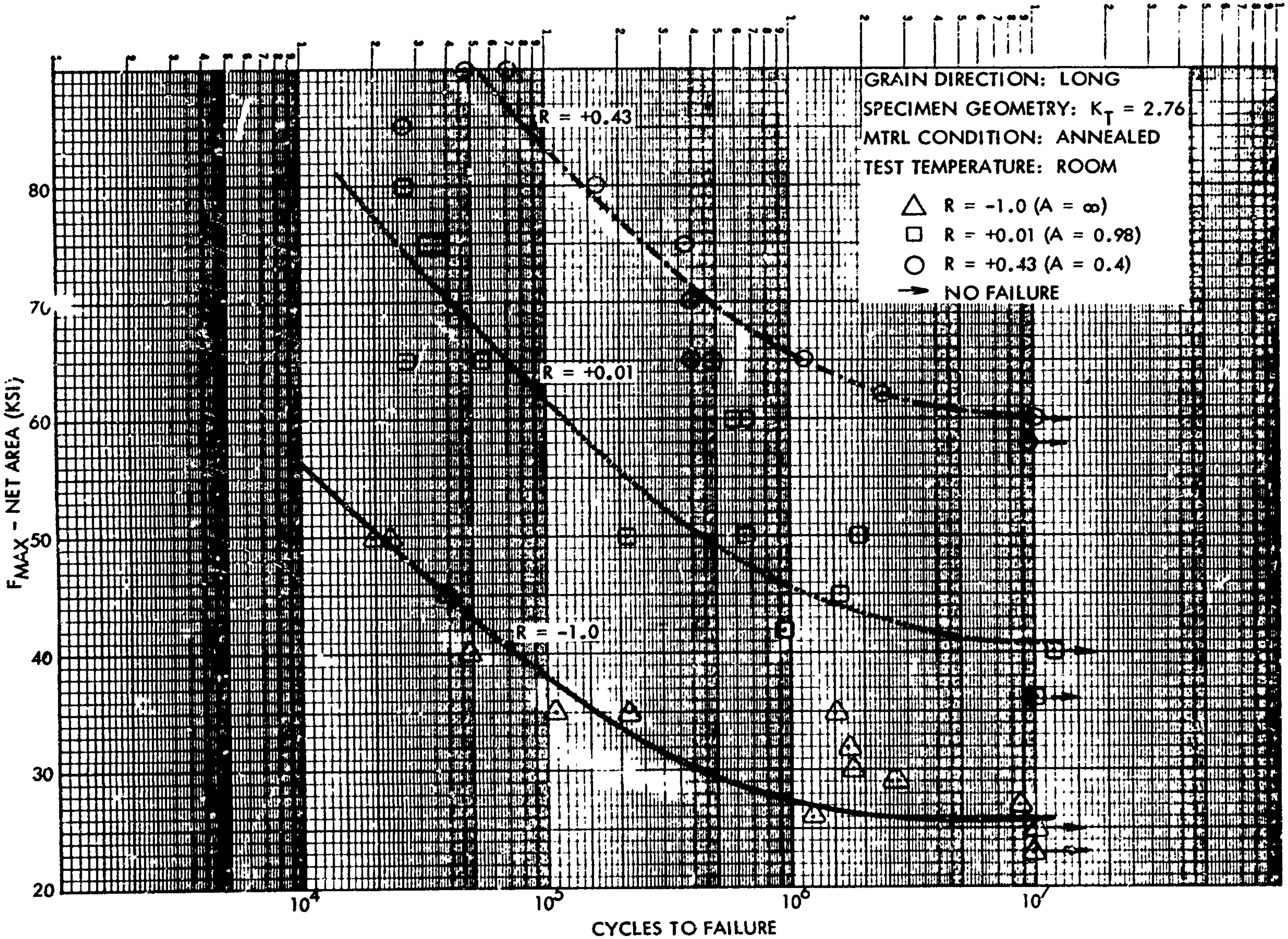


Figure 83. Typical S/N Fatigue Curves for $K_T = 2.76$, (A = , A = 0.98, A = 0.4) Ti-6Al-6V-2Sn Extrusions at Room Temperature

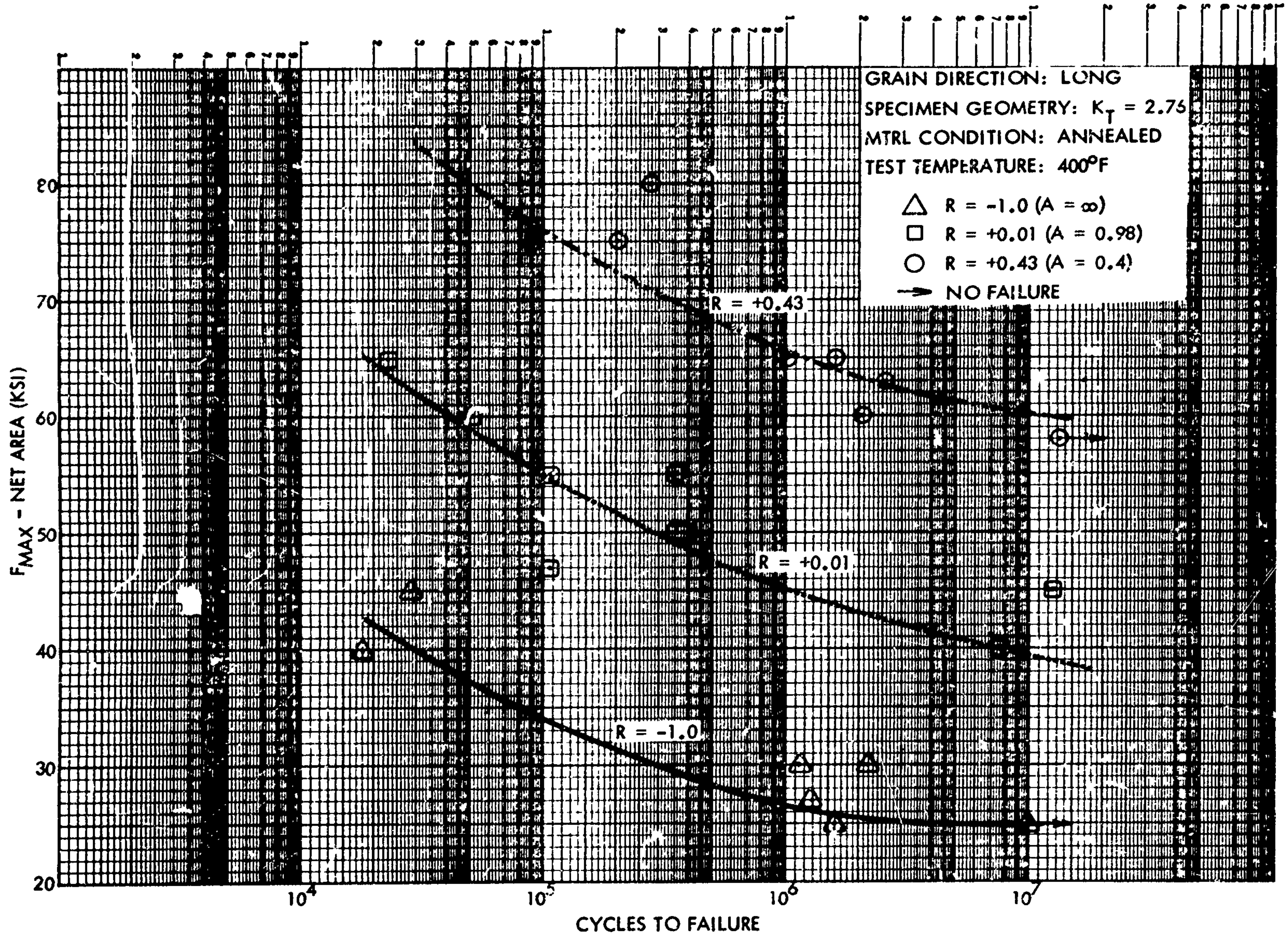


Figure 84. Typical S/N Fatigue Curves for K_T = 2.76, (A = ∞, A = 0.98, A = 0.4) Ti-6Al-6V-2Sn Extrusions at 400F

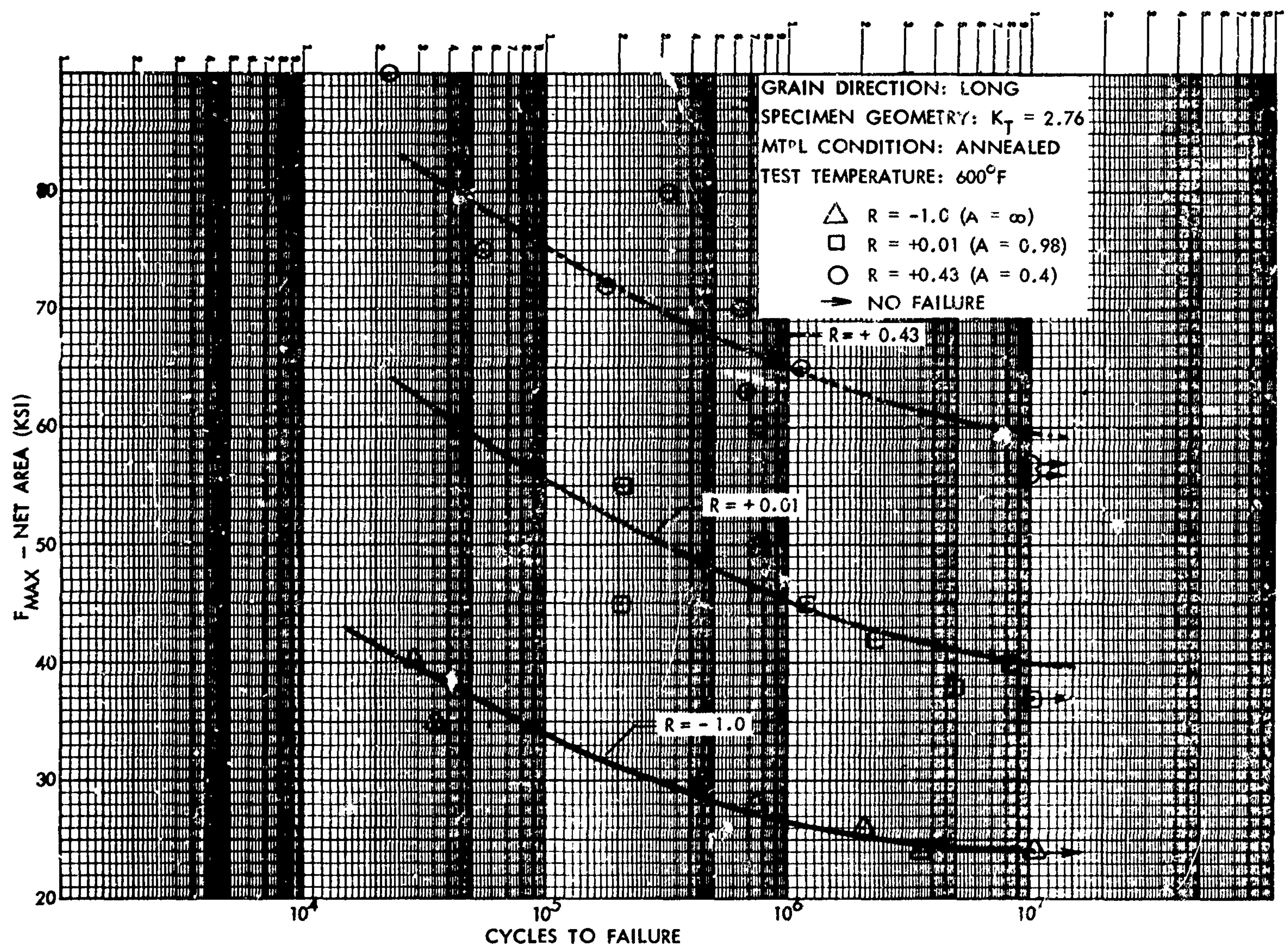


Figure 85. Typical S/N Fatigue Curves for K_T = 2.76 (A = ∞, A = 0.98, A = 0.4) Ti-6Al-6V-2Sn Extrusions at 600F

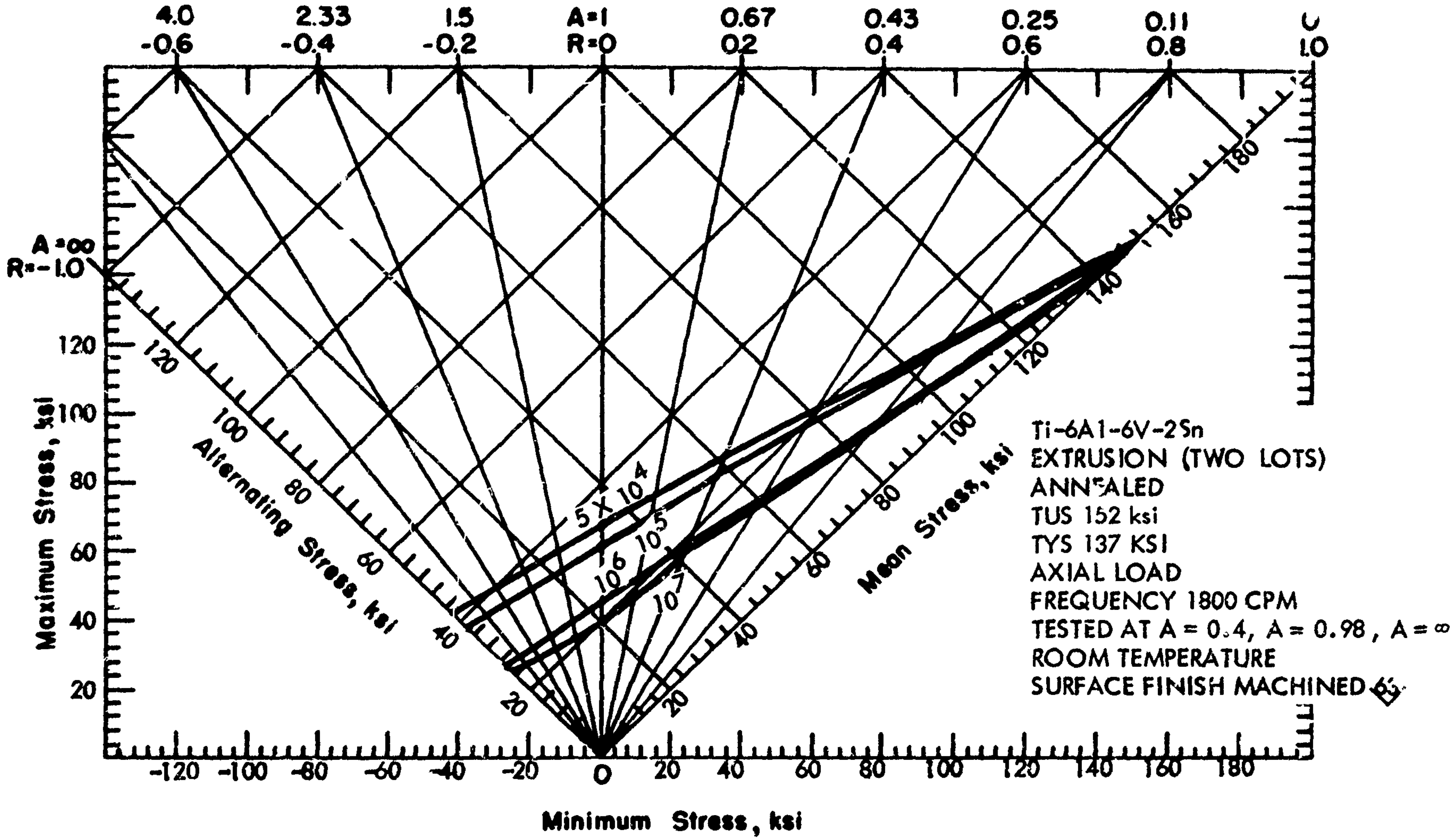


Figure 86. Constant-life Fatigue Diagram for Notched Ti-6Al-6V-2Sn Annealed Extrusions at Room Temperature

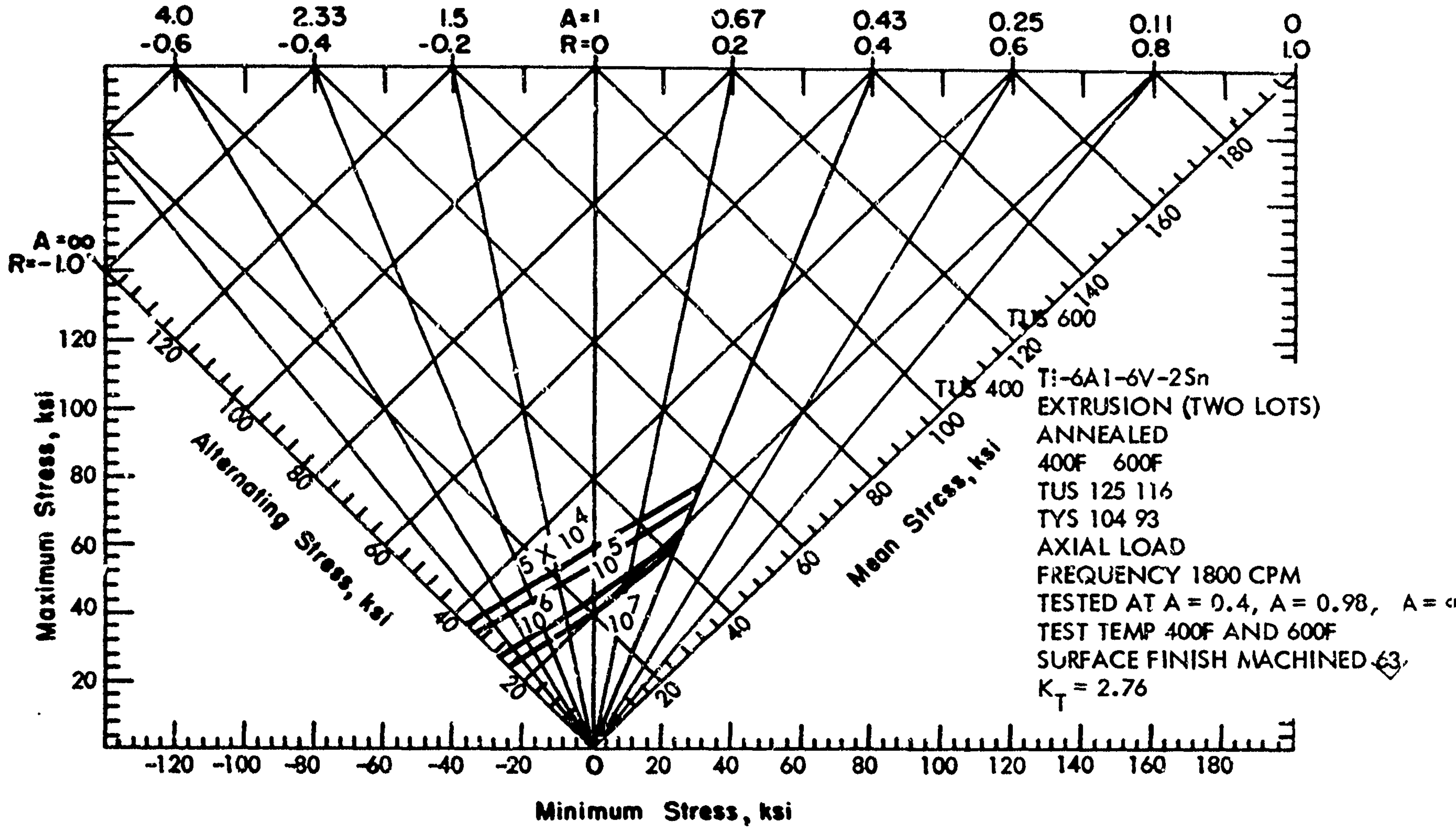


Figure 87. Constant-life Fatigue Diagram for Notched Ti-6Al-6V-2Sn Annealed Extrusions at 400F and 600F

Section VI

CONCLUSIONS AND RECOMMENDATIONS

This program has developed data on annealed titanium extrusions to illustrate where the product form possesses advantages over other materials and other forms of titanium when properly applied in aerospace applications. Extruded products are uniform in properties in the section, in its length, and do not possess abnormal directional characteristics. Data indicate that materials from different vendors and from different heats have closely related properties, and that the relationship of properties as affected by environment or application are consistent.

Within the scope of the testing in this program, MIL-HDBK-5 values could not be developed because of the restrictions on the volume of data which could be generated. Sufficient direction and verification was obtained to establish trends and relationships necessary to establish design data.

Titanium extrusions offer advantages in cost and in environmental suitability.

(1) Because of shape flexibility, savings are usual in material and machining in the type of section where extrusion is adaptable. While machining is required to provide a surface and tolerances suitable for use, machining costs and material costs are generally lower than other heavy product forms.

(2) In high temperature applications creep characteristics of extrusions appear to be superior to other product forms because of the beta worked metallurgical structure. At applications up to 600F, creep does not appear to be a significant factor, while other product forms may require consideration of creep in order to provide satisfactory life.

(3) The beta-worked structure of extrusions appears to offer advantages in delayed failure characteristics in corrosive environments. Recent studies of other product forms have shown the desirability of processing or heat treatment in the beta field in order to achieve better toughness and delayed failure characteristics.

In application of titanium extrusions consideration must be given to other effects of its manner of production and its metallurgical structure. Ductility is generally considered to be lower for beta processed material than for material processed in the alpha-beta field. This may have definite effects on forming characteristics and may make use of such products as alpha-beta

processed sheet preferable. Other properties however seem to be of the same order of magnitude as those of other product forms produced with the lower temperature final processing.

Trends shown by this study indicate that temperature effects on extruded products do not conform to those published in MIL-HDBK-5 for other products. Derived property values should be based on extrusion data to insure proper application. In this respect, it should be pointed out that beta-processed material, or beta heat-treated material, in any product form will be having increased usage, and that verification of property relationships for this type material will be required.

To achieve the long range objectives of this program, action should be taken in the following areas:

(1) Room temperature mechanical property data can at present be established on a specification basis on tensile properties and on compressive yield strength based on vendor guarantees. Sufficient vendor data exists to establish A and B values for Ti-6A-4V. Data points on Ti-8Al-1Mo-1V and Ti-6Al-6V-2Sn may be more limited when evaluated from Handbook standpoint. Vendor data on compression properties exists in reasonable depth in all alloys.

In establishing values and determining properties, it is suggested that date of production be considered as a variable. Definite changes in property trends have been observed based on refinements, or changes in production techniques. This has been particularly true in Ti-8Al-1Mo-1V, with elimination of furnace cooling, and in Ti-6Al-6V-2Sn where original production was directed toward the special requirements of a single application.

Tentative values for other properties can be established using industry accumulated test data in these areas.

(2) Property determination programs should be instituted to provide design data for beta processed sheet, plate, and bar. Current trends for application indicate that this processing will be of increasing importance in gages over approximately 0.062 inch.

(3) Property determination programs should be instituted to provide design data for heat treated and aged (STA) extrusions, and the "Overaged" extrusion where intermediate property levels are established to provide desirable secondary characteristics such as more usable forming temperatures in conjunction with strengths higher than annealed products.

(4) Studies of rapid heating-rapid load creep characteristics, including repeat cycle effects should be continued to determine specific effects on supersonic aircraft under temperature override conditions, and other vehicles such as spacecraft on re-entry.

Appendix

TABULATION OF TEST RESULTS

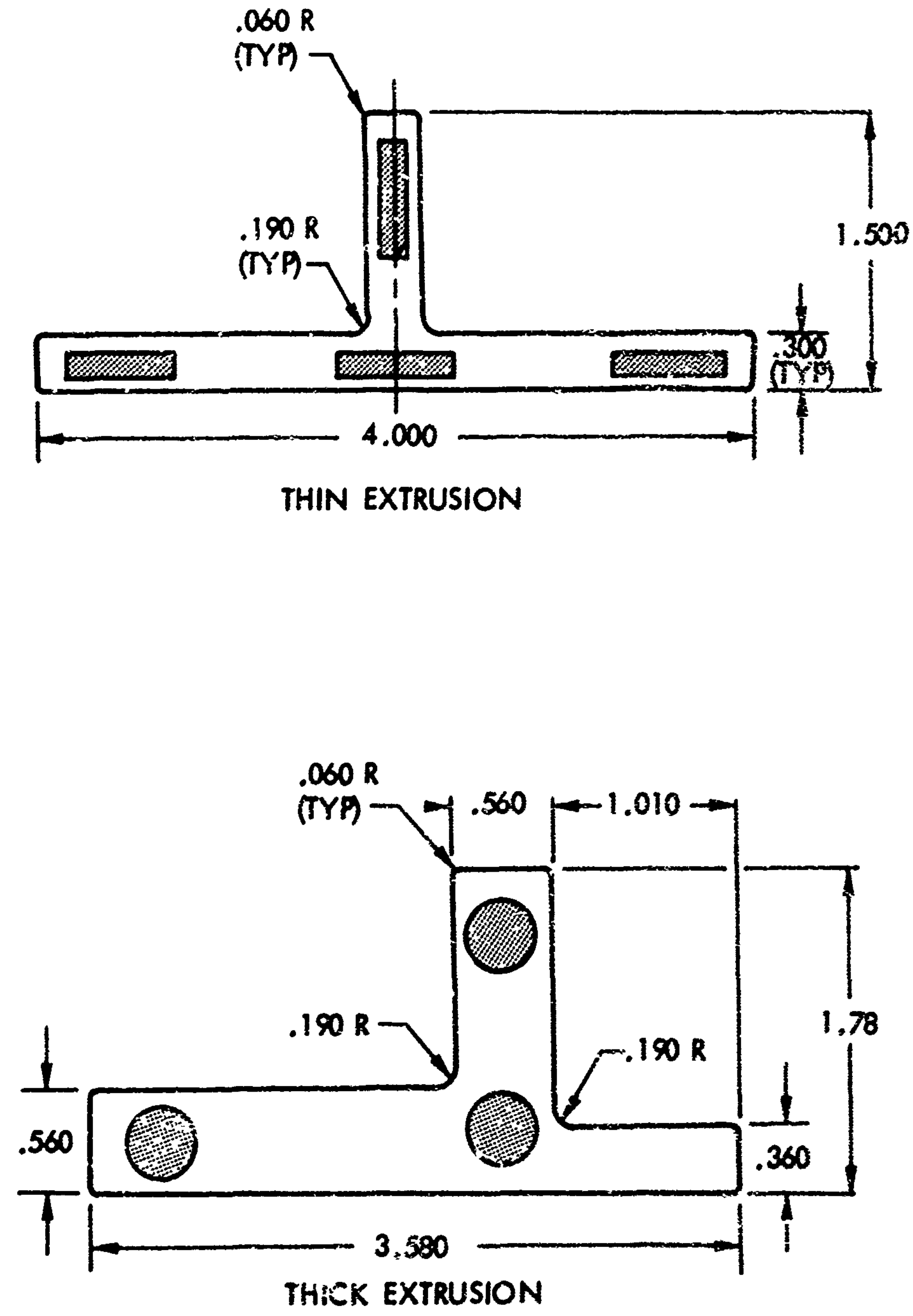
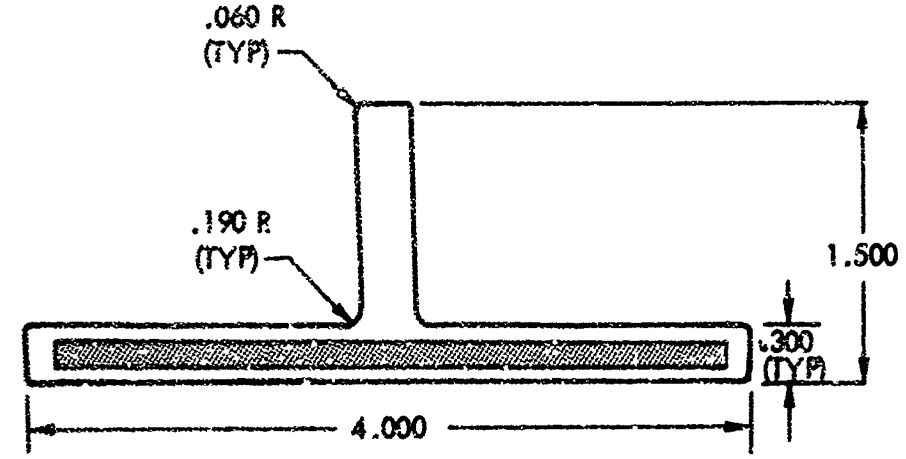
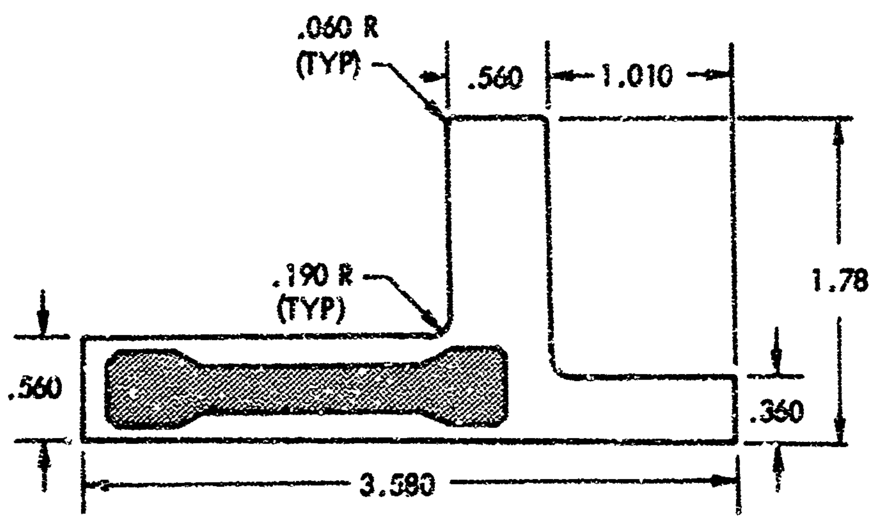


Figure 88. Typical Cross Section Locations Longitudinal Specimens

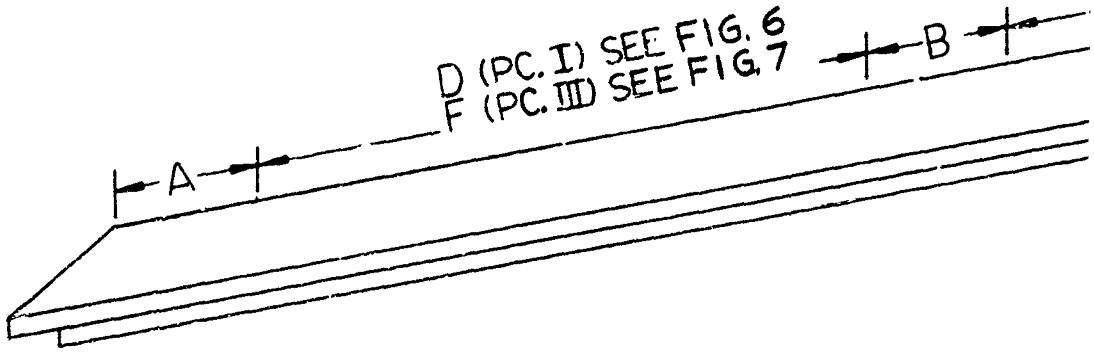


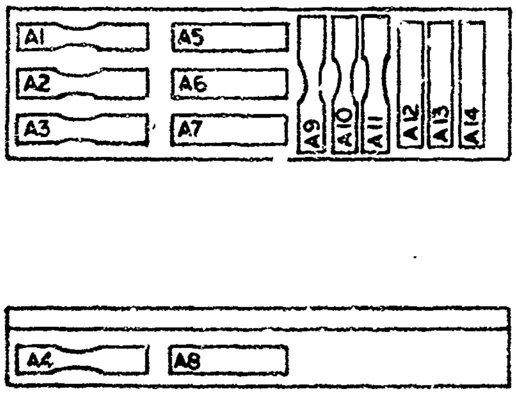
THIN EXTRUSION

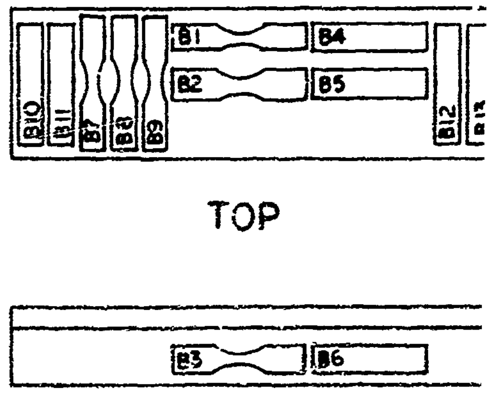


THICK EXTRUSION

Figure 89. Typical Cross Section Locations Transverse Specimens







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SIDE

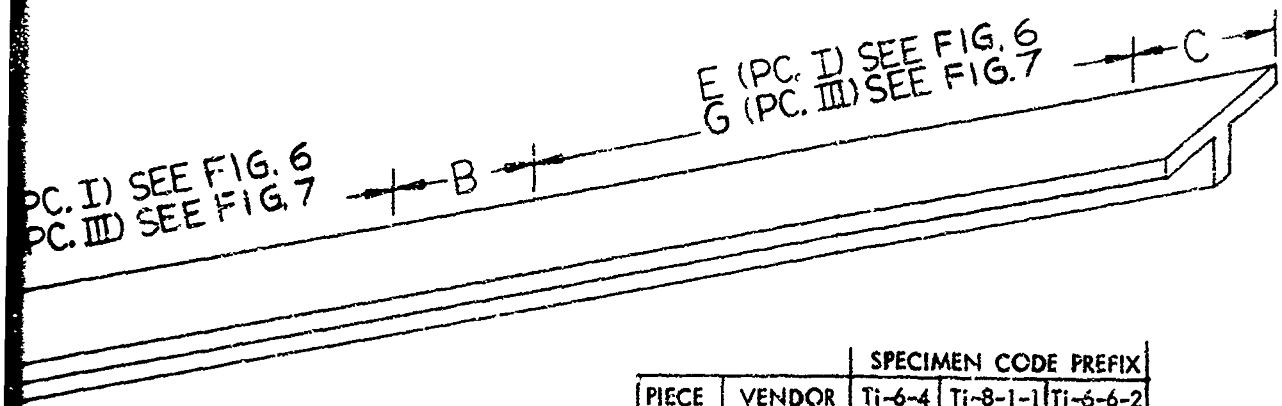
BLOCK A

SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG
A1 THRU A4	TENSILE, LONGIT.	FIG. 11
A5 THRU A8	COMPRESSION, LONGIT.	FIG. 12
A9, A10, A11	TENSILE, TRANSVERSE	FIG. 11
A12, A13, A14	COMPRESSION, TRANS.	FIG. 12

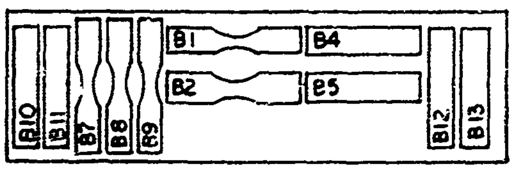
BLOCK B

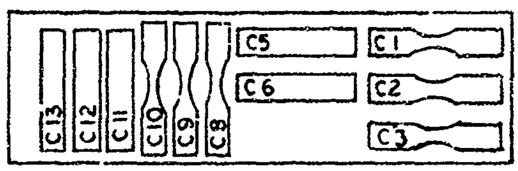
SPECIMEN IDENTIFICATION	TYPE TEST	REF DW
B1, B2, B3	TENSILE, LONGIT.	
B4, B5, B6	COMPRESSION, LONGIT.	
B7, B8, B9	TENSILE, TRANSVERSE	
B10 THRU B15	COMPRESSION, TRANS.	

1



		SPECIMEN CODE PREFIX		
PIECE	VENDOR	Ti-6-4	Ti-8-1-1	Ti-6-6-2
I	HARVEY	A	F	L
III	HARPER	C	H	N





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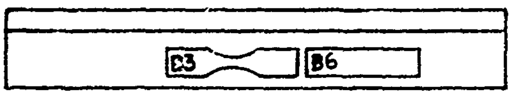
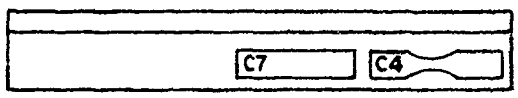




SIDE

BLOCK B

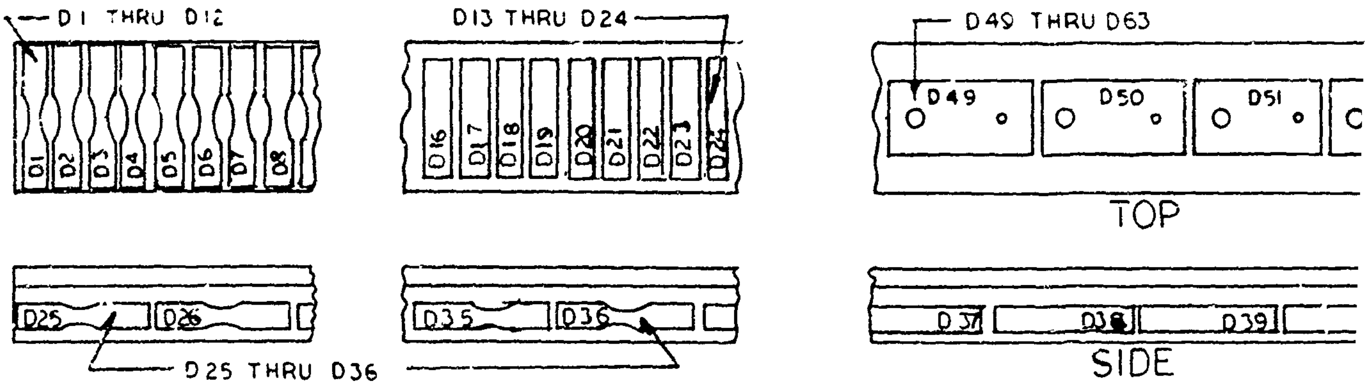
SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG
B1, B2, B3	TENSILE, LONGIT.	FIG 11
B4, B5, B6	COMPRESSION, LONGIT.	FIG 12
B7, B8, B9	TENSILE, TRANSVERSE	FIG 11
B10 THRU B13	COMPRESSION, TRANS.	FIG 12

BLOCK C

SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG
C1 THRU C4	TENSILE, LONGIT.	FIG. 11
C5, C6, C7	COMPRESSION, LONGIT.	FIG. 12
C8, C9, C10	TENSILE, TRANS.	FIG. 11
C11, C12, C13	COMPRESSION, TRANS.	FIG. 12

Figure 90. Specimen Locations, Pieces I and III (Part of)

2



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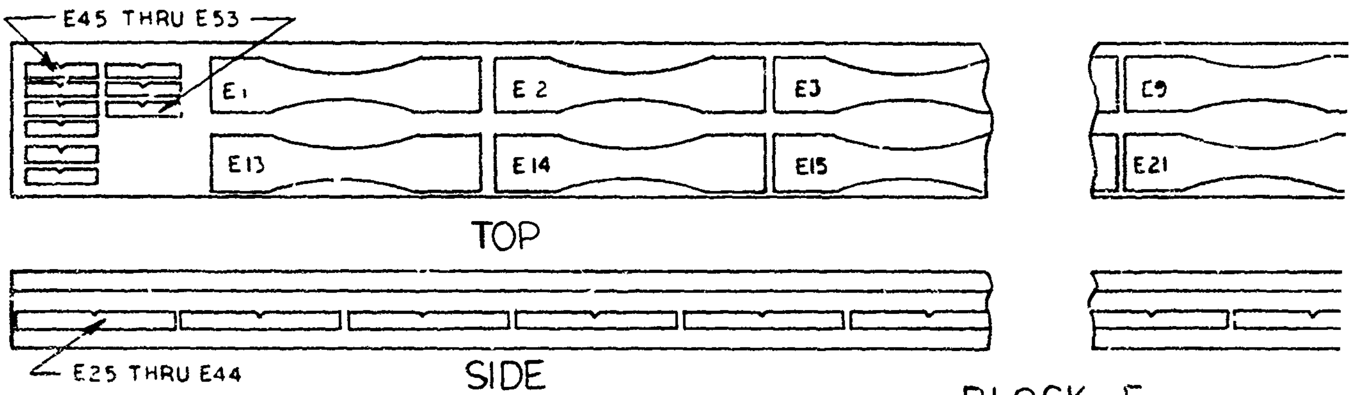
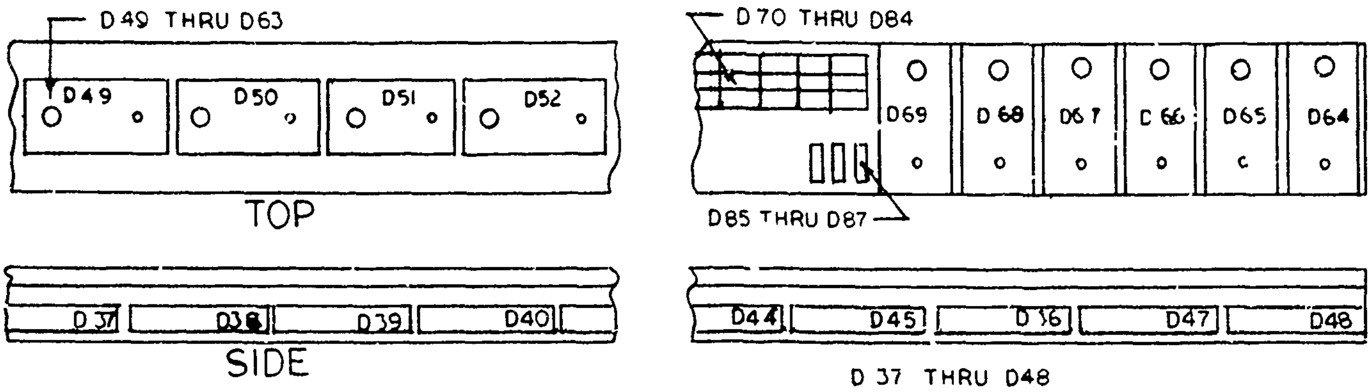


BLOCK E

BLOCK D

SPECIMEN IDENTIFICATION	TEST TYPE	REFERENCE DWG
D1 THRU D12	TENSILE, TRANSVERSE	FIG 11
D13 THRU D24	COMPRESSION, TRANS.	FIG. 12
D25 THRU D36	TENSILE, LONGIT.	FIG. 11
D37 THRU D48	COMPRESSION, LONGIT.	FIG. 12
D49 THRU D63	BEARING, LONGIT.	FIG. 14
D64 THRU D69	BEARING, TRANS.	FIG. 14
D70 THRU D84	SHEAR, LONGIT.	FIG. 13
D85, D86, D87	SHEAR, TRANS.	FIG. 13

1



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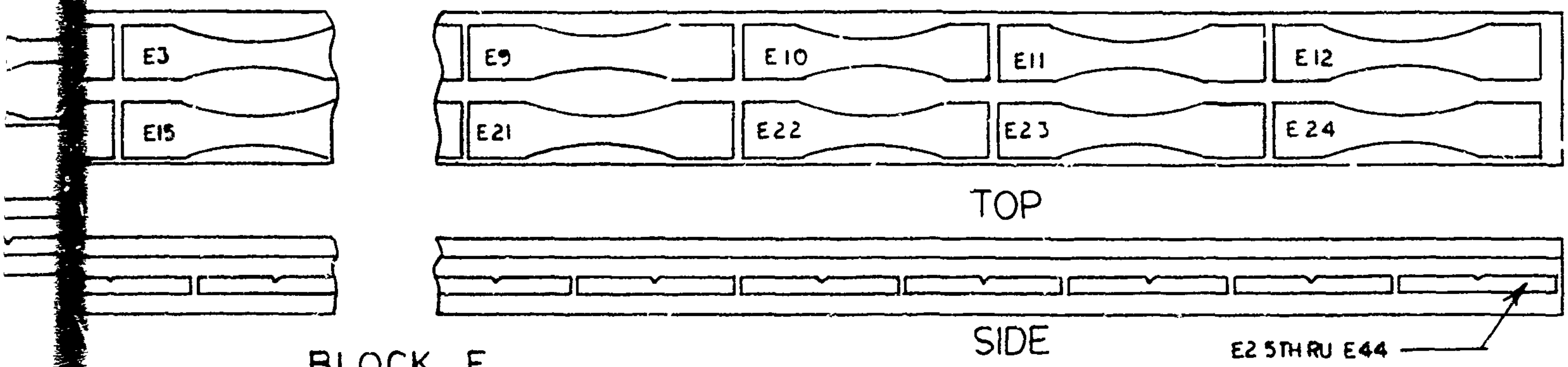


BLOCK E

SPEC IDEN		REFERENCE DWG
E1		FIG. 11
E25		FIG. 12
E45		FIG. 11
		FIG. 12
		FIG. 14
		FIG. 14
		FIG. 18
		FIG. 13

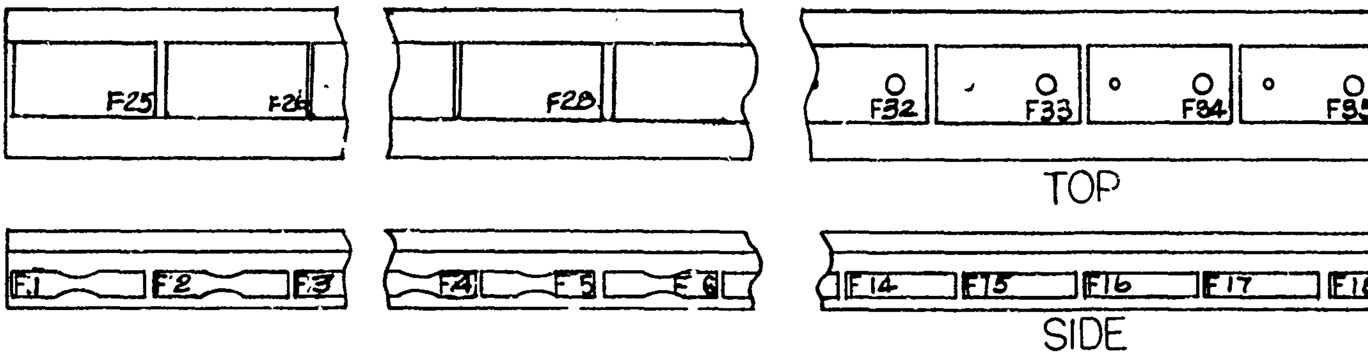
BLOCK E

SPECIMEN IDENTIFICATION	TEST TYPE	REFERENCE DWG
E1 THRU E24	CREEP, STRESS RUPTURE	FIG. 15
E25 THRU E44	FRACTURE TOUGHNESS DELAYED FAILURE	FIG. 19
E45 THRU E53	CHARPY IMPACT	FIG. 17

		SPECIMEN CODE PREFIX		
PIECE	VENDOR	Ti-6-4	Ti-8-1-1	Ti-6-6-2
I	HARVEY	A	F	L

Figure 91. Specimen Locations, Piece I (Cont)

2



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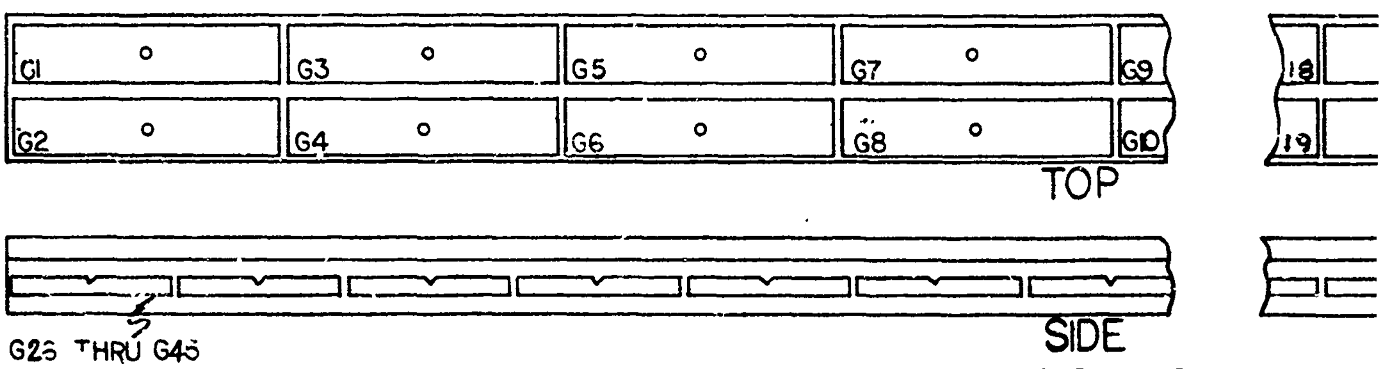


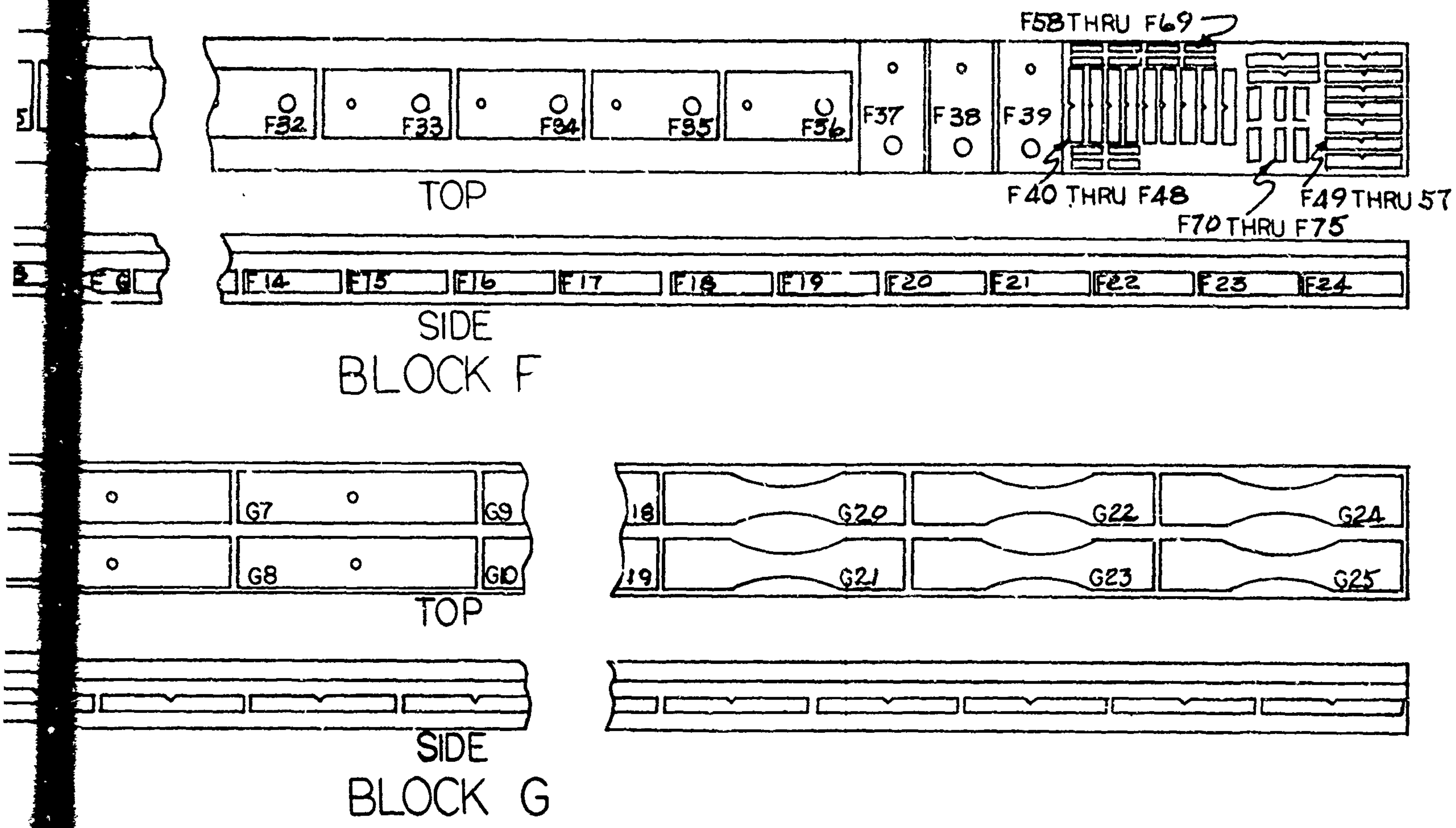
BLOCK G

BLOCK F

SPECIMEN IDENTIFICATION	TEST TYPE	REFERENCE DWG
F1 THRU F12	TENSILE, LONGITUD.	FIG. 11
F13 THRU F 24	COMPRESSION, LONGITUD.	FIG. 12
F25 THRU F36	BEARING, LONGITUD.	FIG. 14
F37 F 38 F39	BEARING, TRANS.	FIG. 14
F40 THRU F48	CHARPY, TRANS.	FIG. 17
F49 THRU F57	CHARPY, LONGIT.	FIG. 17
F58 THRU F69	SHEAR, LONGITUD.	FIG. 13
F70 THRU F75	SHEAR, TRANS.	FIG. 13

SPECIME IDENTIFIC
GI THRU
G16 THR
G26 THR

1



E

EN ICA		REFERENCE DWG
U G		FIG. 11
HRU D.	ITUD	FIG. 12
RU D.		FIG. 14 FIG. 14 FIG. 17 FIG. 17 FIG. 13 FIG. 13

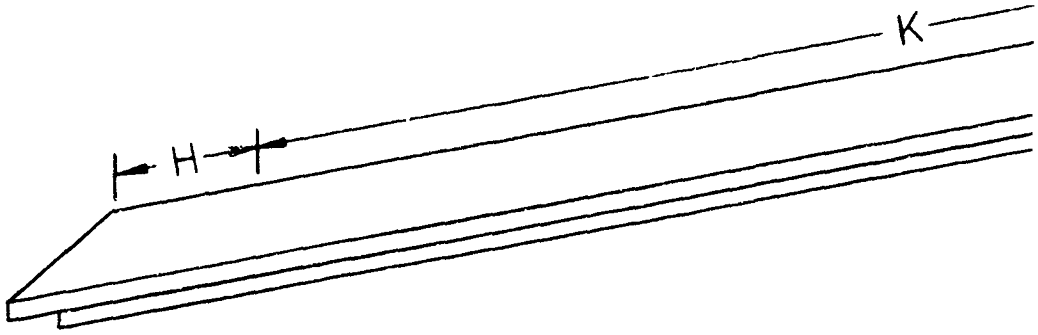
BLOCK G

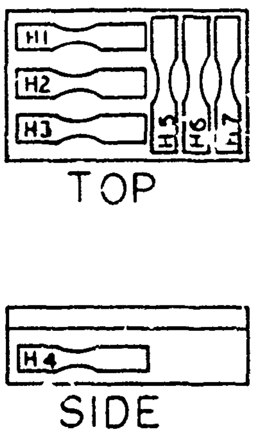
SPECIMEN IDENTIFICATION	TEST TYPE	REFERENCE DWG
G1 THRU G15	NOTCHED FATIGUE $(K_t=2.7)$	FIG. 21
G16 THRU G25	SMOOTH FATIGUE $(K_t=1.0)$	FIG. 20
G26 THRU G45	FRACTURE TOUGHNESS/ DELAYED FAILURE	FIG. 19

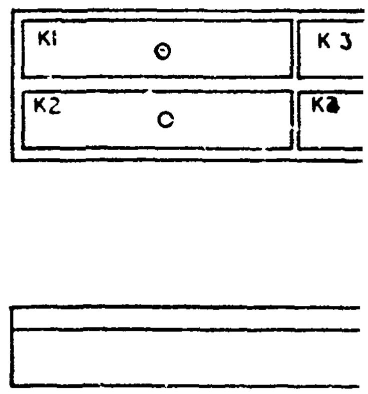
		SPECIMEN CODE PREFIX		
PIECE	VENDOR	Ti-6-4	Ti-8-1-1	Ti-6-6-2
III	HARPER	C	H	N

Figure 92. Specimen Locations, Piece III (Cont)

2







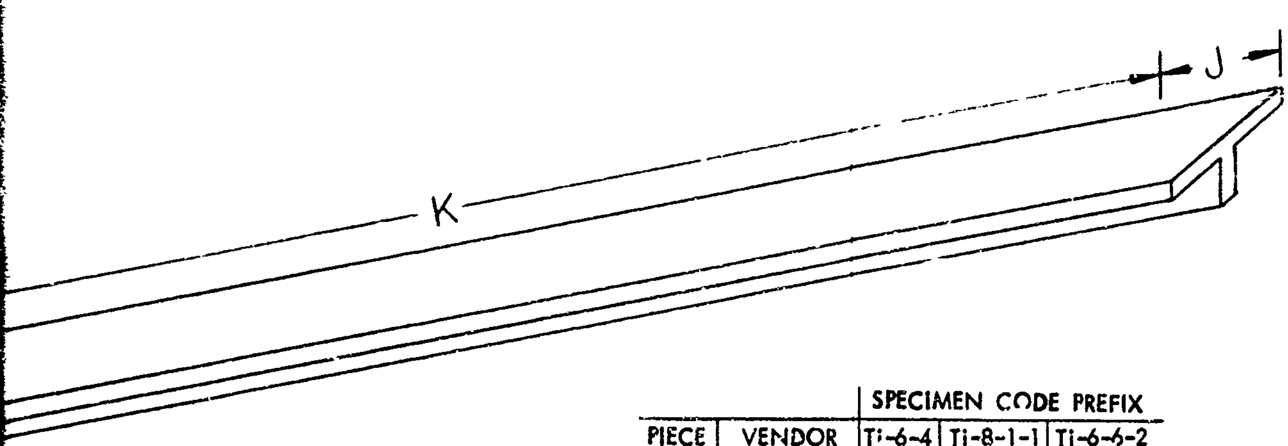
BLOCK H

SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG
H1 THRU H4	TENSILE, LONGIT	FIG. 11
H5, H6, H7	TENSILE, TRANSVERSE	FIG. 11

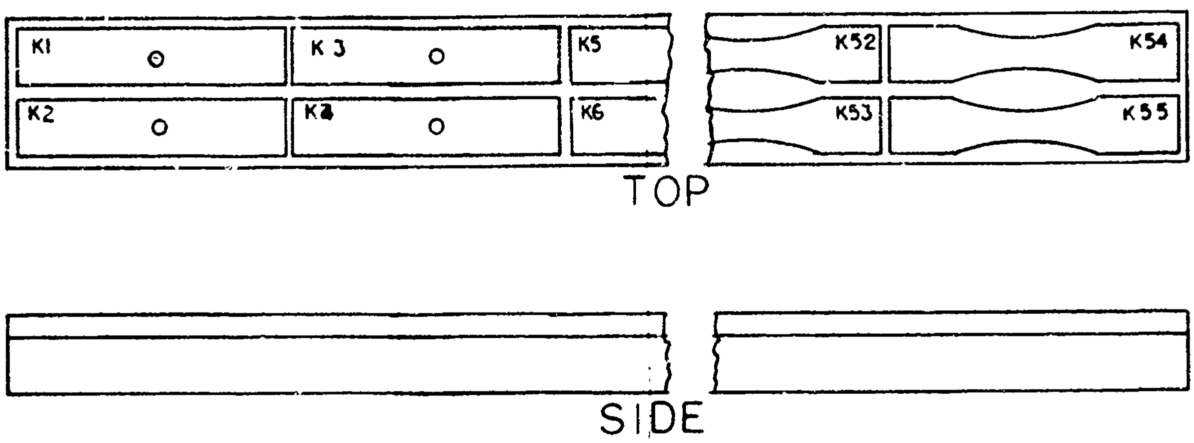
BLOCK J

SPECIMEN IDENTIFICATION	TYPE TEST
J1, J2, J3	TENSILE, TRANSVERSE

1



		SPECIMEN CODE PREFIX		
PIECE	VENDOR	Ti-6-4	Ti-8-1-1	Ti-6-6-2
II	HARVEY	B	G	M
IV	HARPER	D	J	P



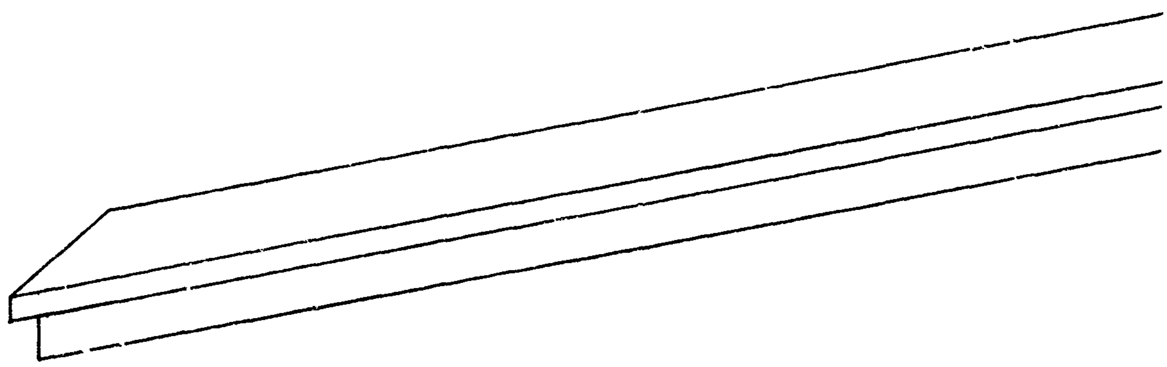
BLOCK J

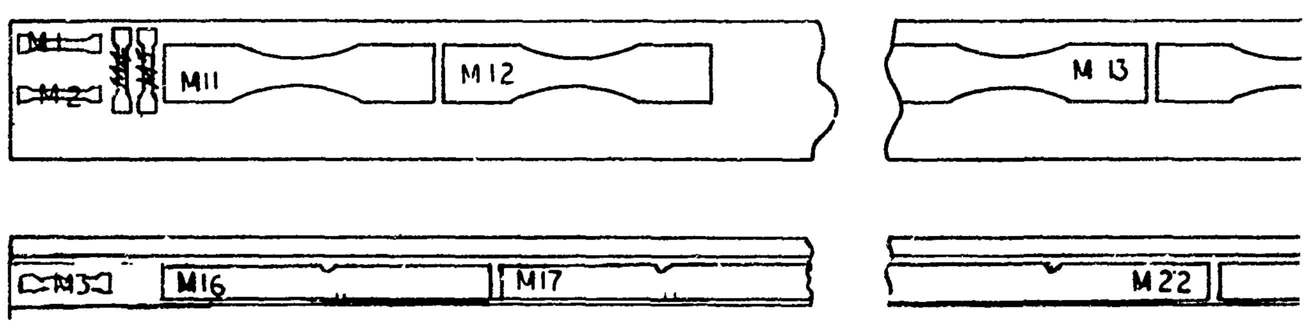
SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG
J1,J2,J3	TENSILE, TRANSVERSE	FIG. 11

BLOCK K

SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG
K1 THRU K45	NOTCHED FATIGUE (K_T = 2.7)	FIG. 21
K46 THRU K55	SMOOTH FATIGUE (K_T = 1.0)	FIG. 20

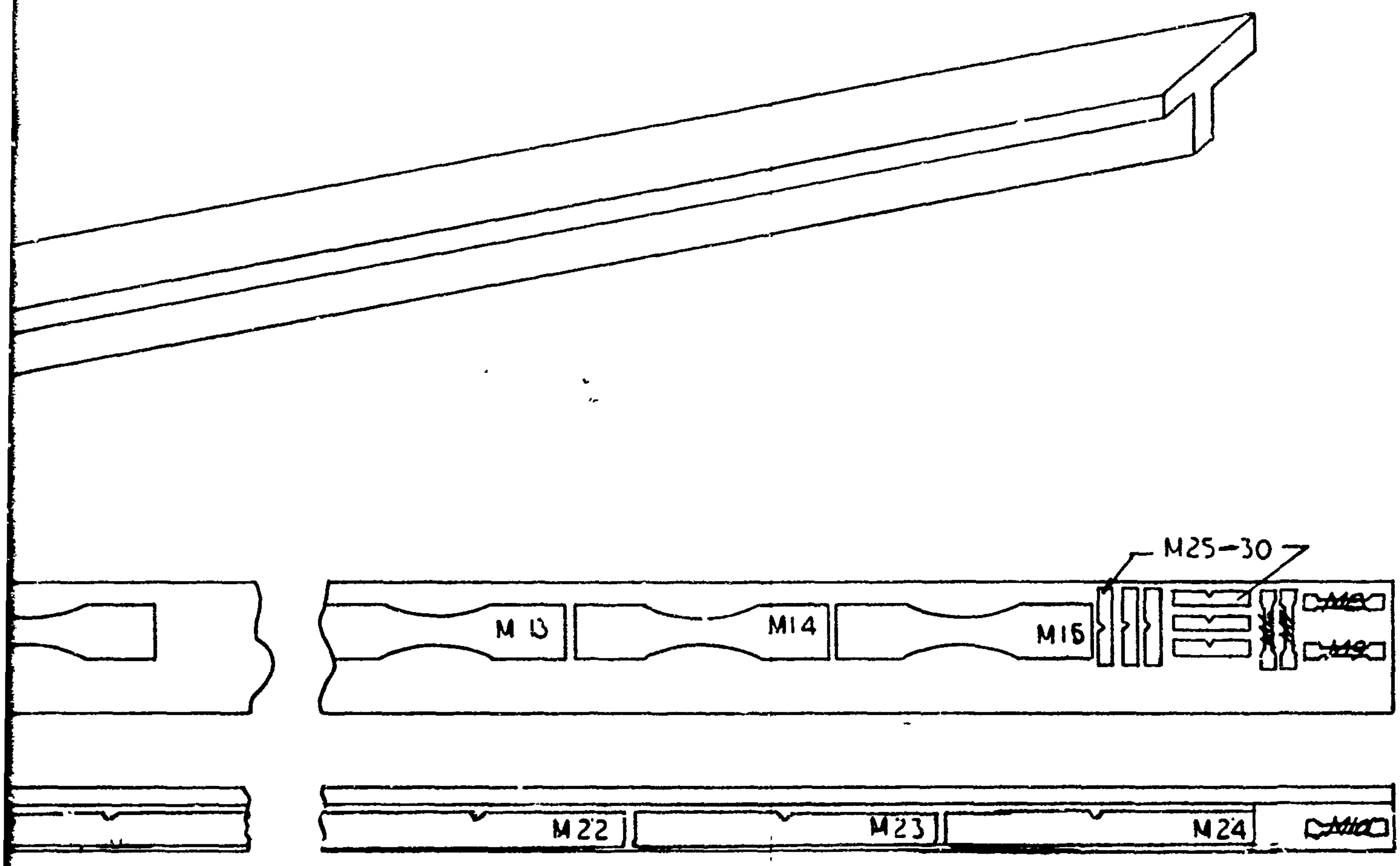
Figure 93. Specimen Locations, Pieces II and IV





SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG.
M1, M2, M3	TENSILE LONGITUDINAL	FIG. 1
M4 THRU M7	TENSILE TRANSVERSE	FIG. 1
M8, M9, M10	TENSILE LONGITUDINAL	FIG. 1
M11 THRU M15	FATIGUE SMOOTH K_T=1.0	FIG. 2
M16 THRU M24	FRACTURE TOUGHNESS DELAYED FAILURE	FIG. 1
M25, M26, M27	CHARPY TRANSVERSE	FIG. 1
M28, M29, M30	CHARPY LONG	FIG. 1

1



SPECIMEN IDENTIFICATION	TYPE TEST	REFERENCE DWG.
M1, M2 M3	TENSILE LONGITUDINAL	FIG. 10
M4 THRU M7	TENSILE TRANSVERSE	FIG. 10
M8, M9, M10	TENSILE LONGITUDINAL	FIG. 10
M11 THRU M15	FATIGUE SMOOTH K_T=1.0	FIG. 20
M16 THRU M24	FRACTURE TOUGHNESS DELAYED FAILURE	FIG. 18
M25, M26, M27	CHARPY TRANSVERSE	FIG. 16
M28, M29, M30	CHARPY LONG	FIG. 16

		SPECIMEN CODE PREFIX		
PIECE	VENDOR	Ti-6-4	Ti-8-1-1	Ti-6-6-2
V	HARVEY	E	K	R

2

Figure 94. Specimen Locations, Piece V, Thick Extrusion

TABLE XVII TENSILE TEST SUMMARY

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-4	Thin (Fig.1)	AD25	L	-110	173	157	12
		AD26			174	164	12
		AD27			172	163	12
		CF1			179	162	12
		CF2			174	162	14
		CF3		-110	174	162	13
		AA1		Room	142	125	13
		AA2			141	125	17
		AA3			142	126	14
		AA4			141	128	16
		AB1			144	127	16
		AB2			142	126	15
		AB3			141	124	15
		AC1			145	130	14
		AC2					
		AC3			141	128	12
		AC4			142	128	14
		BH1			140	125	14
		BH2			140	123	12
		BH3			143	126	17
		BH4			141	124	16
		CA1			147	130	14
		CA2			143	125	16
		CA3			146	129	15
		CA4			143	127	18
		CB1			145	135	13
		CB2			144	128	15
		CB3			144	128	16
Ti-6-4	Thin (Fig.1)	CC1	L	Room	143	128	14

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-4	Thin (Fig.1)	CC2	L	Room	146	129	11
		CC3			146	131	15
		CC4			144	130	16
		DH1			146	132	16
		DH2			143	127	16
		DH3			145	130	16
		DH4		Room	149	136	14
		AD28		400	110	90	15
		AD29			112		16
		AD30			110	88	20
		CF4			113	93	20
		CF5			113	94	18
		CF6		400	112	92	20
		AD31		600	100	76	16
		AD32			103	77	16
		AD33			100	79	17
		CF7			102	79	18
		CF8			101	72	18
		CF9		600	101	80	17
		AD34		800	92	73	17
		AD35			93	73	17
		AD36			93	73	16
		CF10			96	73	14
		CF11			95	75	19
		CF12	L	800	94	73	18
		AD1	T	-110	170	160	12
		AD2			172	162	11
		AD3		-110	169	161	11
Ti-6-4	Thin (Fig.1)	AA9	T	Room	142	127	14

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-4	Thin (Fig.1)	AA10	T	Room	142	128	14
		AA11			141	126	14
		AB7			142	127	13
		AB8			143	127	14
		AB9			143	128	11
		AC8			141	127	14
		AC9			142	126	13
		AC10			142	127	15
		BH5			143	126	15
		BH6			142	126	14
		BH7			145	129	14
		BJ1			141	124	11
		BJ2			145	130	15
		BJ3			140	125	15
		CA9			145	129	15
		CA10			146	130	14
		CA11			146	130	14
		CB7			145	130	15
		CB8			146	129	15
		CB9			146	130	14
		CC8			146	131	15
		CC9			145	128	14
		CC10			146	129	14
		DH5			146	130	13
		DH6			146	129	14
		DH7			146	130	14
		DJ1			146	130	17
		DJ2			150	133	14
Ti-6-4	Thin (Fig.1)	DJ3	T	Room	144	128	14

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-4	Thin (Fig.1)	AD4	T	400	109	86	16
		AD5			110	88	16
		AD6		400	111	90	15
		AD7		600	102	78	15
		AD8			103	79	17
		AD9		600	103	80	16
		AD10		800	93	71	16
		AD11			93	72	16
	Thin (Fig.1)	AD12	T	800	94	72	16
	Thick (Fig.2)	EM1	L	Room	143	129	14
		EM2			140	125	14
		EM3			141	126	14
		EM8			144	130	14
		EM9			141	127	14
		EM10	L		142	128	14
		EM4	T		143	130	14
		EM5			142	133	14
		EM6			144	131	14
Ti-6-4	Thick (Fig.2)	EM7	T	Room	144	130	14
Ti-8-1-1	Thin (Fig.1)	FD25	L	-110	170	161	12
		FD26			167	159	12
		FD27			168	161	12
		HF1			155	143	16
		HF2			156	142	14
		HF3		-110	156	143	16
		FA1		Room	138	125	13
		FA2			135	121	16
		FA3			141	125	13
Ti-8-1-1	Thin (Fig.1)	FA4	L	Room	138	123	14

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-8-1-1	Thin (Fig.1)	FB1	L	Room	141	125	15
		FB2			135	121	18
		FB3			137	121	15
		FC1			144	129	15
		FC2			134	121	18
		FC3			141	126	15
		FC4			141	127	15
		GH1			134	118	21
		GH2			144	127	16
		GH3			143	124	19
		GH4			139	122	19
		HA1			134	118	15
		HA2			129	114	18
		HA3			136	122	18
		HA4			134	121	17
		HB1			134	119	17
		HB2			131	116	16
		HB3			134	120	16
		HC1			134	120	16
		HC2			131	116	17
		HC3			137	124	16
		HC4			132	118	16
		JH1			136	122	18
		JH2			133	119	16
		JH3			134	119	13
		JH4		Room	135	121	18
		FD28		400	115	89	18
		FD29			115	89	18
Ti-8-1-1	Thin (Fig.1)	FD30	L	400	115	88	19

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-8-1-1	Thin (Fig.1)	HF4	L	400	106	85	20
		HF5			105	86	19
		HF6		400	106	85	19
		FD31		600	107	81	18
		FD32			108	80	20
		FD33			108	81	20
		HF7			95	65	19
		HF8			96	72	23
		HF9		600	94	70	19
		FD34		800	99	72	19
		FD35			99	72	20
		FD36			99	73	20
		HF10			88	64	20
		HF11			88	62	23
		HF12	L	800	89	64	19
		FD25	T	-110	170	161	12
		FD26			167	159	12
		FD27		-110	168	161	12
		FA9		Room	137	122	12
		FA10			138	124	15
		FA11			138	126	16
		FB7			138	123	15
		FB8			137	122	15
		FB9			136	122	15
		FC8			136	120	15
		FC9			136	121	15
		FC10			138	123	16
		GH5			137	120	17
Ti-8-1-1	Thin (Fig.1)	GH6	T	Room	137	121	17

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-8-1-1	Thin (Fig.1)	GH7	T	Room	138	120	17
		GJ1			138	121	15
		GJ2			137	120	15
		GJ3			138	122	15
		HA9			133	118	14
		HA10			134	119	14
		HA11			133	118	
		HB7			133	118	
		HB8			132	117	
		HB9			132	117	
		HC8			132	116	
		HC9			132	117	
		HC10			132	117	
		JH5			136	123	
		JH6			134	119	
		JH7			134	119	
		JJ1			133	117	
		JJ2			132	116	
		JJ3		Room	133	118	
		FD4		400	113	89	18
		FD5			112	88	18
		FD6		400	114	90	18
		FD7		600	106	80	20
		FD8			103	78	16
		FD9		600	105	80	18
		FD10		800	96	72	18
		FD11			93	69	18
Ti-8-1-1	Thin (Fig.1)	FD12	T	800	95	72	20

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-8-1-1	Thick (Fig.2)	KM1	L	Room	138	126	12
		KM2			132	119	14
		KM3			134	122	15
		KM8			138	126	15
		KM9			133	121	15
		KM10	L		132	120	15
		KM4	T		136	123	15
		KM5			136	123	13
		KM6			136	123	14
Ti-8-1-1	Thick (Fig.2)	KM7	T	Room	138	127	15
Ti-6-6-2	Thin (Fig.1)	LD25	L	-110	190	180	9
		LD26			189	178	9
		LD27			187	177	11
		NF1			172	162	13
		NF2			173	162	12
		NF3		-110	173	162	14
		LA1		Room	157	140	15
		LA2			154	138	14
		LA3			157	140	15
		LA4			164	144	15
		LB1			158	139	15
		LB2			157	132	14
		LB3			156	-	15
		LC1			159	142	13
		LC2			158	140	14
		LC3			159	143	13
		LC4			158	141	14
		MH1			160	140	16
Ti-6-6-2	Thin (Fig.1)	MH2	L	Room	158	138	16

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-6-2	Thin (Fig.1)	MH3	L	Room	154	136	15
		MH4			157	137	17
		NA1			153	136	15
		NA2			147	134	16
		NA3			147	133	18
		NA4			150	135	17
		NB1			146	132	15
		NB2			143	131	17
		NB3			146	133	18
		NC1			148	134	15
		NC2			145	132	17
		NC3			150	135	16
		NC4			145	132	17
		PH1			145	134	20
		PH2			142	131	21
		PH3			146	135	18
		PH4		Room	147	136	19
		LD28		400	125	101	16
		LD29			125	100	17
		LD30			126	100	17
		NF4			125	104	18
		NF5			125	105	21
		NF6		400	125	104	20
		LD31		600	121	100	19
		LD32			121	94	18
		LD33			121	95	17
		NF7			116	93	17
		NF8			117	93	19
Ti-6-6-2	Thin (Fig.1)	NF9	L	600	115	92	16

TABLE XVII TENSILE TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-6-2	Thin (Fig.1)	LD34	L	800	108	86	17
		LD35			108	86	24
		LD36			110	88	18
		NF10			108	89	19
		NF11			107	86	17
		NF12	L	800	108	89	17
		LD1	T	-110	191	180	9
		LD2			190	181	9
		LD3		-110	193	182	9
		LA9		Room	160	139	11
		LA10			157	140	11
		LA11			159	142	13
		LB7			160	141	15
		LB8			159	141	12
		LB9			160	145	14
		LC8			160	145	13
		LC9			161	146	13
		LC10			157	142	14
		MH5			159	139	14
		MH6			160	141	15
		MH7			159	140	15
		MJ1			161	143	14
		MJ2			161	143	14
		MJ3			159	141	13
		NA9			152	136	16
		NA10			153	137	17
		NA11			152	137	15
		NB7			151	135	15
Ti-6-6-2	Thin (Fig.1)	NB8	T	Room	150	135	17

TABLE XVII TENSILE TEST SUMMARY (Concluded)

Alloy	Section	Specimen I.D.	Grain Dir.	Test Temp. (°F)	TUS (ksi)	TYS (ksi)	Elong. (%)
Ti-6-6-2	Thin (Fig.1)	NB9	T	Room	151	135	16
		NC8			150	134	15
		NC9			150	136	15
		NC10			151	135	15
		PH5			148	134	18
		PH6			148	134	19
		PH7			148	133	16
		PJ1			149	133	17
		PJ2			150	136	16
		PJ3		Room	150	136	17
		LD4		400	134	107	16
		LD5			132	108	14
		LD6		400	133	108	14
		LD7		600	126	98	15
		LD8			127	100	14
		LD9		600	125	98	15
		LD10		800	114	91	18
		LD11			114	91	16
	Thin (Fig.1)	LD12	T	800	115	92	16
	Thick (Fig.2)	RM1	L	Room	157	142	12
		RM2			156	138	13
		RM3			154	137	15
		RM8			156	140	13
		RM9			154	136	15
		RM10	L		154	137	14
		RM4	T		161	144	13
		RM5			161	145	13
		RM6			160	145	12
Ti-6-6-2	Thick (Fig.2)	RM7	T	Room	162	148	11

TABLE XVIII COMPRESSION TEST SUMMARY

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-6-4	Thin (Fig. 1)	AD37	L	-110	---
		AD38			172
		AD39			174
		CF13			179
		CF14			171
		CF15		-110	171
		AA5		Room	---
		AA6			137
		AA7			139
		AA8			137
		AB4			139
		AB5			139
		AB6			137
		AC5			139
		AC6			138
		AC7			139
		CA5			142
		CA6			140
		CA7			142
		CA8			142
		CB4			142
		CB5			142
		CB6			142
		CC5			---
		CC6			140
		CC7		Room	141
		AD40		400	92
Ti-6-4	Thin (Fig. 1)	AD41	L	400	93

TABLE XVIII COMPRESSION TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-6-4	Thin (Fig. 1)	AD42	L	400	93
		CF16			97
		CF17			99
		CF18		400	100
		AD43		600	80
		AD44			78
		AD45			80
		CF19			83
		CF20			83
		CF21		600	84
		AD46		800	79
		AD47			---
		AD48			76
		CF22			78
		CF23			77
		CF24	L	800	79
		AD13	T	-110	173
		AD14			172
		AD15		-110	176
		AA12		Room	139
		AA13			139
		AA14			138
		AB10			139
		AB11			138
		AB12			140
		AB13			142
		AC11			138
		AC12			138
Ti-6-4	Thin (Fig. 1)	AC13	T	Room	139

TABLE XVIII COMPRESSION TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-6-4	Thin	CA12	T	Room	144
		CA13			147
		CA14			145
		CB10			146
		CB11			145
		CB12			143
		CB13			142
		CC11			144
		CC12			143
		CC13		Room	146
		AD16		400	95
		AD17			96
		AD18		400	96
		AD19		600	82
		AD20			82
		AD21		600	82
		AD22		800	77
		AD23			77
Ti-6-4		AD24	T	800	78
Ti-8-1-1		FD37	L	-110	169
		FD38			167
		FD39			174
		HF13			162
		HF14			---
		HF15		-110	163
		FA5		Room	137
		FA6			135
Ti-8-1-1	Thin (Fig. 1)	FA7	L	Room	139

TABLE XVIII COMPRESSION TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-8-1-1	Thin (Fig. 1)	FA8	L	Room	134
		FB4			137
		FB5			135
		FB6			136
		FC5			140
		FC6			131
		FC7			138
		HA5			132
		HA6			129
		HA7			133
		HA8			131
		HB4			128
		HB5			131
		HB6			132
		HC5			130
		HC6			128
		HC7		Room	132
		FD40		400	99
		FD41			96
		FD42			98
		HF16			92
		HF17			92
		HF18		400	91
		FD43		600	82
		FD44			83
		FD45			82
		HF19			77
		HF20			77
Ti-[illegible]-1	Thin (Fig. 1)	HF21	L	600	77

TABLE XVIII COMPRESSION TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-8-1-1	Thin (Fig. 1)	FD46	L	800	78
		FD47			78
		FD48			77
		HF22			70
		HF23			70
		HF24	L	800	70
		FD13	T	-110	173
		FD14			173
		FD15		-110	---
		FA12		Room	140
		FA13			138
		FA14			138
		FB10			137
		FB11			138
		FB12			138
		FB13			139
		FC11			139
		FC12			139
		FC13			139
		HA12			135
		HA13			136
		HA14			134
		HB10			133
		HB11			132
		HB12			133
		HB13			132
		HC11			132
Ti-8-1-1	Thin (Fig. 1)	HC12	T	Room	135

TABLE XVIII COMPRESSION TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-8-1-1	Thin (Fig. 1)	HC13	T	Room	133
		FD16		400	100
		FD17			98
		FD18		400	98
		FD19		600	84
		FD20			---
		FD21		600	84
		FD22		800	79
		FD23			80
Ti-8-1-1		FD24	T	800	75
Ti-6-6-2		LD37	L	-110	194
		LD38			196
		LD39			196
		NF13			182
		NF14			186
		NF15		-110	184
		LA5		Room	154
		LA6			154
		LA7			154
		LA8			153
		LB4			156
		LB5			152
		LB6			154
		LC5			156
		LC6			155
		LC7			156
		NA5			147
		NA6			148
Ti-6-6-2	Thin (Fig. 1)	NA7	L	Room	150

TABLE XVIII. COMPRESSION TEST SUMMARY (Continued)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-6-6-2	Thin (Fig. 1)	NA8	L	Room	148
		NB4			148
		NB5			147
		NB6			149
		NC5			149
		NC6			146
		NC7		Room	148
		LD40		400	---
		LD41			114
		LD42			114
		NF16			111
		NF17			110
		NF18		400	110
		LD43		600	102
		LD44			104
		LD45			102
		NF19			102
		NF20			101
		NF21		600	101
		LD46		800	94
		LD47			96
		LD48			97
		NF22			96
		NF23			95
		NF24	L	800	95
		LD13	T	-110	201
		LD14			199
Ti-6-6-2	Thin (Fig. 1)	LD15	T	-110	202

TABLE XVIII COMPRESSION TEST SUMMARY (Concluded)

Alloy	Section	Specimen I.D.	Grain Direct.	Test Temp (°F)	CYS 0.2% (ksi)
Ti-6-6-2	Thin (Fig. 1)	LA12	T	Room	159
		LA13			158
		LA14			160
		LB10			157
		LB11			155
		LB12			157
		LB13			159
		LC11			158
		LC12			161
		LC13			157
		NA12			152
		NA13			154
		NA14			153
		NB10			---
		NB11			151
		NB12			149
		NB13			153
		NC11			151
		NC12			148
		NC13		Room	149
		LD16		400	117
		LD17			118
		LD18		400	116
		LD19		600	105
		LD20			105
		LD21		600	106
		LD22		800	103
		LD23			100
Ti-6-6-2	Thin (Fig. 1)	LD24	T	800	98

TABLE XIX TENSILE MODULUS SUMMARY

Alloy	Specimen Number	E_t (x 10^6 psi)	
Ti-6-4	AA2	16.8	
	AB2	16.9	
	AC1	17.0	
	Average		16.9
Ti-8-1-1	FA2	17.5	
	FB2	17.6	
	FC2	17.6	
	Average		17.6
Ti-6-6-2	LA2	16.3	
	LB2	15.8	
	LC2	16.2	
	Average		16.1

ROOM TEMPERATURE, LONGITUDINAL SPECIMENS

TABLE XX BEARING TEST SUMMARY

Alloy	Specimen ID	Test Temp.	Grain Direction	e/D	Ultimate Bearing Strength(ksi)	Bearing Yield Strength(ksi)
Ti-6-4	AD49	$-110^{\circ}F$	L	2.0	329	294
	AD50				$\triangle 1$	$\triangle 1$
	AD51	$-110^{\circ}F$			332	299
	AVG				$\boxed{330}$	$\boxed{296}$
	AD52	RT			$\triangle 1$	$\triangle 1$
	AD53				$\triangle 1$	$\triangle 1$
	AD54				295	250
	AVG				$\boxed{295}$	$\boxed{250}$
	CF28				265	233
	CF29				293	2[illegible]
	CF30	RT			270	240
	AVG				$\boxed{276}$	$\boxed{240}$
	AD58	$400^{\circ}F$			219	190
	AD59				207	195
	AD60				204	186
	AVG				$\boxed{210}$	$\boxed{190}$
	CF31				226	193
	CF32				231	188
	CF33	$400^{\circ}F$			227	198
	AVG				$\boxed{228}$	$\boxed{193}$
	AD61	$600^{\circ}F$			208	173
	AD62				209	170
	AD63				187	174
	AVG				$\boxed{201}$	$\boxed{172}$
	CF34				199	166
	CF35				195	169
Ti-6-4	CF36	$600^{\circ}F$	L	2.0	218	170
	AVG				$\boxed{204}$	$\boxed{168}$

TABLE XX BEARING TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp.	Grain Direction	e/D	Ultimate Bearing Strength(ksi)	Bearing Yield Strength(ksi)
Ti-6-4	AD64	RT	T	2.0	308	259
	AD65				294	252
	AD66				302	260
	AVG				301	257
	CF37				300	245
	CF38				298	266
	CF39	RT			290	255
	AVG				296	255
	AD67	400°F			215	194
	AD68				237	195
	AD69	400°F	T	2.0	223	193
	AVG				225	194
	AD55	RT	L	1.5	248	210
	AD56				244	207
	AD57				239	207
	AVG				244	208
	CF25				253	217
	CF26				240	205
	CF27	RT	L	1.5	247	209
Ti-6-4	AVG				247	210
Ti-8-1-1	FD49	-110°F	L	2.0	323	282
	FD50				△1	△1
	FD51	-110°F			△1	△1
	AVG				323	282
	FD52	RT			279	228
	FD53				296	240
Ti-8-1-1	FD54	RT	L	2.0	300	252
	AVG				292	240

TABLE XX BEARING TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp.	Grain Direction	e/D	Ultimate Bearing Strength(ksi)	Bearing Yield Strength(ksi)
Ti-8-1-1	HF28	RT	L	2.0	262	224
	HF29				283	220
	HF30	RT			266	218
	AVG				270	221
	FD58	400°F			221	189
	FD59				221	181
	FD60				219	184
	AVG				220	185
	HF31				214	169
	HF32				219	171
	HF33	400°F			212	176
	AVG				215	172
	FD61	600°F			199	174
	FD62				186	160
	FD63				192	167
	AVG				192	167
	HF34				197	154
	HF35				186	151
	HF36	600°F	L		192	150
	AVG				192	152
	FD64	RT	T		290	249
	FD65				299	251
	FD66				285	247
	AVG				291	249
	HF37				310	269
	HF38				314	255
Ti-8-1-1	HF39	RT	T	2.0	326	281
	AVG				323	268

TABLE XX BEARING TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp.	Grain Direction	e/D	Ultimate Bearing Strength(ksi)	Bearing Yield Strength(ksi)
Ti-8-1-1	FD67	400°F	T	2.0	226	190
	FD68				220	190
	FD69	400°F	T	2.0	221	195
	AVG				222	192
	FD55	RT	L	1.5	239	203
	FD56				241	197
	FD57				237	203
	AVG				239	201
	HF25				228	194
	HF26				225	189
Ti-8-1-1	HF27	RT		1.5	213	177
	AVG				222	187
Ti-6-6-2	LD49	-110°F		2.0	344	323
	LD50				370	335
	LD51	-110°F			△1	△1
	AVG				357	329
	LD52	RT			309	274
	LD53				340	288
	LD54				300	275
	AVG				316	279
	NF28				297	260
	NF29				308	256
	NF30	RT			287	246
	AVG				297	254
	LD58	400°F			254	219
	LD59				260	228
Ti-6-6-2	LD60	400°F	L	2.0	251	224
	AVG				255	224

TABLE XX BEARING TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp.	Grain Direction	e/D	Ultimate Bearing Strength(ksi)	Bearing Yield Strength(ksi)
Ti-6-6-2	NF31	400°F	L	2.0	254	219
	NF32				244	216
	NF33	400°F			253	219
	AVG				250	218
	LD61	600°F			225	208
	LD62				214	207
	LD63				209	201
	AVG				216	205
	NF34				245	204
	NF35				229	201
	NF36	600°F	L		234	199
	AVG				236	201
	LD64	RT	T		344	298
	LD65				340	291
	LD66				339	282
	AVG				341	290
	NF37				310	269
	NF38				314	255
	NF39	RT			326	284
	AVG				317	270
	LD67	400°F			244	207
	LD68				254	227
	LD69	400°F	T	2.0	247	231
	AVG				248	222
	LD55	RT	L	1.5	262	228
	LD56				270	235
Ti-6-6-2	LD57				274	-
	AVG	RT	L	1.5	269	231

TABLE XX BEARING TEST SUMMARY (Concluded)

Alloy	Specimen ID	Test Temp.	Grain Direction	e/D	Ultimate Bearing Strength(ksi)	Bearing Yield Strength(ksi)
Ti-6-6-2	NF25	RT	L	1.5	247	218
	NF26				258	223
Ti-6-6-2	NF27	RT	L	1.5	250	228
	AVG				252	223
Abnormal deformation at loading hole						

TABLE XXI SHEAR TEST SUMMARY

Alloy	Specimen ID	Test Temp	Grain Direction	Double Shear Strength (ksi)
Ti-6-4	AD70	-110°F	L	103
	AD71			108
	AD72			107
	Avg			$\boxed{106}$
	AD73	RT		95
	AD74			94
	AD75			92
	AD76			93
	AD77			90
	AD78			89
	Avg			$\boxed{92}$
	CF58			94
	CF59			91
	CF60			93
	CF61			89
	CF62			90
	CF63			91
	Avg			$\boxed{91}$
	AD79	400°F		79
	AD80			75
	AD81			
	Avg			$\boxed{77}$
	CF64			△1
	CF65			77
	CF66			△1
	Avg			$\boxed{77}$
	AD82	600°F		70
	AD83			70
	AD84			71
Ti-6-4	Avg	600°F	L	$\boxed{70}$

TABLE XXI SHEAR TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp	Grain Direction	Double Shear Strength (ksi)
Ti-6-4	CF67	600°F	L	69
	CF68			69
	CF69	600°F	L	72
	Avg			$\boxed{70}$
	AD85	RT	T	88
	AD86			94
	AD87			95
	Avg			$\boxed{92}$
	CF70			90
	CF71			92
	CF72	RT		94
	Avg			$\boxed{92}$
	CF73	400°F		78
	CF74			77
Ti-6-4	CF75		T	74
	Avg			$\boxed{76}$
Ti-8-1-1	FD70	-110°F	L	102
	FD71			△1
	FD72			103
	Avg			$\boxed{102}$
	FD73	RT		90
	FD74			92
	FD75			93
	FD76			92
	FD77			89
	FD78			90
	Avg			91
	HF58			89
Ti-8-1-1	HF59	RT	L	87

TABLE XXI SHEAR TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp	Grain Direction	Double Shear Strength (ksi)
Ti-8-1-1	HF60	RT	L	88
	HF61			90
	HF62			86
	HF63	RT		86
	Avg			87
	FD79	400°F		78
	FD80			79
	FD81			79
	Avg			79
	HF64			△1
	HF65			△1
	HF66	400°F	L	△1
	Avg			
	FD82	600°F	L	70
	FD83			69
	FD84			68
	Avg			69
	HF67			66
	HF68			68
	HF69	600°F	L	70
	Avg			68
	FD85	RT	T	87
	FD86			88
	FD87			87
	Avg			87
	HF70			90
	HF71			88
Ti-8-1-1	HF72	RT	T	86
	Avg			88

TABLE XXI SHEAR TEST SUMMARY (Continued)

Alloy	Specimen ID	Test Temp	Grain Direction	Double Shear Strength (ksi)
Ti-8-1-1	HF73	400°F	T	△1
	HF74			△1
Ti-8-1-1	HF75	400°F	T	75
	Avg			75
Ti-6-6-2	LD70	-110°F	L	118
	LD71			121
	LD72	-110°F		119
	Avg			119
	LD73	RT		102
	LD74			100
	LD75			101
	LD76			102
	LD77			99
	LD78			100
	Avg			101
	NF58			100
	NF59			100
	NF60			101
	NF61			104
	HF62			101
	NF63	RT		99
	Avg			101
	LD79	400°F		92
	LD80			90
	LD81			89
	Avg			90
	NF64			△1
Ti-6-6-2	NF65	400°F	L	△1

TABLE XXI SHEAR TEST SUMMARY (Concluded)

Alloy	Specimen ID	Test Temp	Grain Direction	Double Shear Strength (ksi)
Ti-6-6-2	NF66	400°F	L	△1
	Avg			
	LD82	600°F	L	82
	LD83			80
	LD84			82
	Avg			81
	NF67			83
	NF68			83
	NF69	600°F	L	84
	Avg			83
	LD85	RT	T	103
	LD86			101
	LD87			102
	Avg			102
	NF70			100
	NF71			99
	NF72	RT		101
	Avg			100
	NF73	400°F		86
	NF74			△1
Ti-6-6-2	NF75	400°F	T	90
	Avg			88

△1 Abnormal failure with bending

TABLE XXII CHARPY IMPACT TEST SUMMARY

Alloy	Spec. Ident.	Grain Direction	Test Temperature (°F)	Impact Strength (ft-lb) .250 Width	Impact Strength (ft-lb) .394 Width
Ti-6-4	AL1	Longitudinal	-110 [1]	7.0	
	AL2			7.0	
	AL3			7.0	
	CL1			6.0	
	CL2			6.5	
	CL3		-110	6.0	
	AE48		72	5.5	
	AE49			5.5	
	AE50			6.5	
	CF52			5	
	CF53			6	
	CF54			6	
	EM28				9
	EM29				8
	EM30		72		8
	AE45		110	6.0	
	AE46			6.0	
	AE47			7.0	
	CF49			7.0	
	CF50			6.4	
	CF51		110	6.0	
	AE51		400	11.0	
	AE52			11.0	
	AE53			11.0	
	CF55			10.5	
	CF56			9.0	
	CF57	Longitudinal	400	9.5	
	CT1	Transverse	-110 [1]	9.0	
	CT2			6.5	
	CT3		-110	9.5	
	CF43		72	14	
	CF44			11	
	CF45			13	
	EM25				9
	EM26				28
	EM27		72		28
	CF40		110	12.0	
	CF41			15.0	
	CF42		110	14.5	
	CF46		400	17.0	
	CF47			16.5	
Ti-6-4	CF48	Transverse	400	16.5	

TABLE XXII CHARPY IMPACT TEST SUMMARY (Continued)

Alloy	Spec. Ident.	Grain Direction	Test Temperature (°F)	Impact Strength (ft-lb) .250 Width	Impact Strength (ft-lb) .394 Width
Ti-8-1-1	FL1	Longitudinal	-110 [1]	10.0	
	FL2			10.0	
	FL3			10.5	
	HL1			10.5	
	HL2			10.5	
	HL3		-110	10.0	
	FE48		72	6	
	FE49			11	
	FE50			10.5	
	HF52			8	
	HF53			11	
	HF54			10	
	KM28				18.5
	KM29				20
	KM30		72		18
	FE45		110	11.5	
	FE46			12.0	
	FE47			12.5	
	HF49			11.0	
	HF50			12.5	
	HF51		110	12.9	
	FE51		400	21.5	
	FE52			21.5	
	FE53			22.0	
	HF55			18.0	
	HF56			17.5	
	HF57	Longitudinal	400	19.0	
	HT1	Transverse	110	14.0	
	HT2			15.0	
	HT3		110	15.0	
	HF43		72	9.5	
	HF44			20.5	
	HF45			18	
	KM25				19
	KM26				17.5
	KM27		72		19.5
	HF40		110	21.5	
	HF41			23.5	
	HF42		110	21	
	HF46		400	24.5	
	HF47			24.5	
Ti-8-1-1	HF48	Transverse	400	22.5	

TABLE XXII CHARPY IMPACT TEST SUMMARY (Concluded)

Alloy	Spec. Ident.	Grain Direction	Test Temperature (°F)	Impact Strength (ft-lb) .250 Width	Impact Strength (ft-lb) .394 Width
Ti-6-6-2	LL1	Longitudinal	-110 △	6.5	
	LL2			6.0	
	LL3			6.5	
	NL1			7.0	
	NL2			5.0	
	NL3		110	6.0	
	LE48		72	11	
	LE49			6	
	LE50			5	
	NF52			5	
	NF53			5	
	NF54			4	
	RM28				5.5
	RM29				4.5
	RM30		72		5.5
	LE45		110	9.5	
	LE46			9.0	
	LE47			10.0	
	NF49			4.5	
	NF50			6.0	
	NF51		110	5.5	
	LE51		400	21.5	
	LE52			21.5	
	LE53			22.0	
	NF55			8.0	
	NF56			8.5	
	NF57	Longitudinal	400	9.5	
	NT1	Transverse	-110 △	10.0	
	NT2			10.0	
	NT3		-110 △	12.5	
	NF43		72	12	
	NF44			13.5	
	NF45			13.0	
	RM25				5
	RM26				5
	RM27		72		5
	NF40		110	12	
	NF41			15.5	
	NF42		110	12.0	
	NF46		400	19.0	
	NF47			16.0	
Ti-6-6-2	NF48	Transverse	400	16.5	

△ Specimens for testing at -110F were fabricated and tested separately from other specimens.

TABLE XXIII FRACTURE TOUGHNESS TEST SUMMARY
(Longitudinal)

Alloy	Spec. Ident.	Test Temp	K_{Ic} (ksi $\sqrt{in}$)
Ti-6-4	AE25	-110F	87
	AE26		86
	AE27		67
	AE28		71
	AE29		67
	AVG		
	CG26		64
	CG27		66
	CG28		65
	CG29		62
	CG30		61
	AVG	-110F	64
	AE30	RT	74
	AE31		72
	AE32		74
	AE33		--
	AE34		73
	AVG		73
	CG31		70
	CG32		61
	CG33		61
	CG34		71
	CG35		66
	AVG		65
	EM16		77
	EM17		81
	EM18		79
Ti-6-4	AVG	RT	79
Ti-8-1-1	FE25	-110F	77
	FE26		76
	FE27		75
	FE28		79
	FE29		74
	AVG		76
	HG26		89
	HG27		92
	HG28		87
	HG29		85
	HG30		91
	AVG	-110F	89
	FE30	RT	79
Ti-8-1-1	FE31	RT	84

TABLE XXIII FRACTURE TOUGHNESS TEST SUMMARY (Continued)
(Longitudinal)

Alloy	Spec. Ident.	Test Temp	K_{Ic} (ksi $\sqrt{in}$)
Ti-8-1-1	FE32	RT	81
	FE33		84
	FE34		85
	AVG		83
	HG31		86
	HG32		90
	HG33		85
	HG34		89
	HG35		90
	AVG		88
	KM16		84
	KM17		91
	KM18		80
Ti-8-1-1	AVG	RT	85
Ti-6-6-2	LE25	-110F	43
	LE26		47
	LE27		44
	LE28		49
	LE29		48
	AVG		46
	NG26		51
	NG27		59
	NG28		60
	NG29		61
	NG30		59
	AVG	-110F	58
	LE30	RT	57
	LE31		61
	LE32		52
	LE33		59
	LE34		60
	AVG		58
	NG31		76
	NG32		74
	NG33		74
	NG34		71
	NG35		68
	AVG		71
	RM16		[illegible]
	RM17		[illegible]
	RM18		[illegible]
Ti-6-6-2	AVG	RT	58

TABLE XXIV DELAYED FAILURE TEST SUMMARY
(Room Temperature, Longitudinal)

Alloy	Spec. Ident.	K_{Ii} (ksi $\sqrt{in}$)	Time (Min)	Notes
Ti-6-4	AE35	55	1	Fail
	AE36	40	3	Fail
	AE37	23	180	No Failure
	AE38	31	120	No Failure
	AE39	42	180	No Failure
	AE40	40	180	No Failure
	AE41	36	6000	No Failure
	AE42	43	6	Fail
	AE43	38	60	No Failure
	AE44	45	3	Fail
	CG36	43	180	No Failure
	CG37	51	3	Fail
	CG38	48	2	Fail
	CG39	45	6780	No Failure
	CG40	52	3	Fail
	CG41	51	3	Fail
	CG42	42	3	Fail
	CG43	42	74	No Failure
	CG44	39	78	No Failure
	CG45	53	1	Fail
	EM19	29	187	No Failure
	EM20	39	1083	No Failure
	EM21	47	5	Fail
	EM22	42	10	Fail
	EM23	42	6015	No Failure
Ti-6-4	EM24	43	90	No Failure
Ti-8-1-1	FE35	40	3	Fail
	FE36	25	180	No Failure
	FE37	36	180	No Failure
	FE38	43	78	Fail
	FE39	35	4	Fail
	FE40	37	180	No Failure
	FE41	34	7020	No Failure
	FE42	43	6	Fail
	FE43	40	6	Fail
	FE44	37	4	Fail
	HG36	34	180	No Failure
	HG37	56	4	Fail
Ti-8-1-1	HG38	40	9	Fail

TABLE XXIV DELAYED FAILURE TEST SUMMARY (Continued)
(Room Temperature, Longitudinal)

Alloy	Spec. Ident.	K_{Ii} (ksi $\sqrt{in}$)	Time (Min)	Notes
Ti-8-1-1	HG39	38	35	Fail
	HG40	36	2700	Fail
	HG41	33	6840	No Failure
	HG42	47	9	Fail
	HG43	50	9	Fail
	HG44	40	80	No Failure
	HG45	41	10	Fail
	KM19	34	181	No Failure
	KM20	36	17	Fail
	KM21	39	6	Fail
	KM22	32	6009	No Failure
	KM23	40	85	No Failure
Ti-8-1-1	KM24	43	5	Fail
Ti-6-6-2	LE35	51	1	Fail
	LE36	43	1	Fail
	LE37	29	180	No Failure
	LE38	34	1	Fail
	LE39	36	1	Fail
	LE40	41	5880	No Failure
	LE41	34	240	No Failure
	LE42	37	1	Fail
	LE43	38	60	No Failure
	LE44	39	60	No Failure
	NG36	37	180	No Failure
	NG37	46	180	No Failure
	NG38	57	2	Fail
	NG39	52	2	Fail
	NG40	42	5640	No Failure
	NG41	46	60	No Failure
	NG42	53	2	Fail
	NG43	51	65	No Failure
	NG44	58	2	Fail
	NG45	63	1	Fail
	RM19	27	185	No Failure
	RM20	36	1055	No Failure
	RM21	51	2	Fail
	RM22	48	2	Fail
	RM23	36	6003	No Failure
Ti-6-6-2	RM24	41	3	Fail

TABLE XXV CREEP TEST SUMMARY

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-6-4	AE-4	109	400F	-	.15	Failed
(TUS 110 TYS 89)	AE-6	108		0	0	
				.0038	1	
				.0052	2	
				.0057	3	
				.0066	68	
				.0067	120	Unloaded
	AE-5	107		0	0	
				.0028	1	
				.0039	2	
				.0046	3	
				.0050	4	
				.0054	17	
				.0060	89	
				.0060	115	Unloaded
	AE-1	105		0	0	
				.0001	1	
				.0008	20	
				.0010	117	
				.0012	261	
				.0012	525	
				.0014	597	
				.0014	964	Unloaded
Ti-8-1-1	FE-2	114		-	.05	Failed
(TUS 115 TYS 89)	FE-6	114		-	0	Failed on Loading
	FE-4	113		0	0	
				.0038	1	
				.0048	2	
				.0057	18	
				.0060	90	
				.0062	162	
				.0062	192	Unloaded
	FE-3	112		0	0	
				0	257	
				.0002	353	
			400F	.0002	426	Unloaded

TABLE XXV CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-8-1-1	FE-1	109	400F	0	0	
				.0001	1	
				.0006	20	
				.0008	260	
				.0008	525	
				.0011	597	
				.0011	988	
Ti-6-6-2	LE-6	130	400F	-	0	Failed on Loading
(TUS 125 TYS 100)	LE-5	128	no measurements		116	Unloaded
	LE-4	126	no measurements		336	Unloaded
	LE-3	124		0	0	
				.0230	1	
				.0373	19	
				.0382	187	
				.0383	595	
				.0391	691	
				.0396	859	
				.0396	960	Unloaded
	LE-2	121		0	0	
				.0013	1	
				.0016	3	
				.0016	5	
				.0020	71	
				.0021	96	
				.0023	167	
				.0023	335	
				.0027	458	Unloaded
	LE-1	119		0	0	
				.0011	1	
				.0014	2	
				.0017	4	
				.0019	20	
				.0019	92	
				.0020	116	
				.002[illegible]	188	
				.00[illegible]2	428	
			400F	.0[illegible]24	596	

TABLE XXV CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-6-6-2	LE-1		400F	.0025	860	
				.0025	940	Unloaded
Ti-6-4	AE-15	100	600F	-	0	Failed on Loading
(TUS 101	AE-19	100.0		0	0	
TYS 77)				.0003	1	
				.0006	2	
				.0008	3	
				.0008	4	
				.0009	5	
				.0014	21	
				.0026	93	
				.0039	261	
				.0044	333	
	AE-17	99		0	0	
				.0006	1	
				.0007	4	
				.0009	5	
				.0013	23	
				.0020	71	
				.0025	147	Unloaded
	AE-13	98		0	0	
				.0006	19	
				.0008	139	
				.0015	235	
				.0018	307	
				.0021	403	
				.0021	643	
				.0024	739	
				.0025	810	
				.0025	978	Unloaded
	AE-16	95		0	0	
				.0004	1	
				.0006	5	
				.0008	24	
				.0011	96	
				.0013	192	
			600F	.0021	264	

TABLE XXV CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-6-4	AE-16	95	600F	.0022	672	
				.0023	768	
				.0023	941	Unloaded
	AE-13	93		0	0	
				.0003	1	
				.0004	3	
				.0008	4	
				.0010	5	
				.0021	22	
				.0027	46	
				.0034	118	
				.0044	214	
				.0048	382	
				.0048	622	
				.0050	718	
				.0051	957	Unloaded
	AE-14	89.0		0	0	
				.0006	1	
				.0006	2	
				.0009	90	
				.0010	498	
				.0010	1097	
				.00105	1169	
	AE-18	79.0		0	0	
				.0006	1	
				.0006	2	
				.0008	22	
				.0026	477	
				.0032	645	
Ti-8-1-1	FE-22	107		-	0	Failed on Loading
(TUS 107 TYS 81)	FE-18	106		-	0	Failed on Loading
	FE-13	105		0	0	
				.0002	1	
			600F	.0002	141	Unloaded

TABLE XXV CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-8-1-1	FE-14	105.0	600F	0	0	
				.0004	1	
				.0006	2	
				.0009	20	
				.0018	235	
				.0021	475	
			600F	.0024	643	
	FE-23	104	-	-	0	Failed on Loading
	FE-21	102.0	600F	0	0	
				.0002	1	
				.0003	2	
				.0004	3	
				.0007	19	
				.0010	91	
				.0013	258	
				.0017	426	
	FE-24	100.0		0	0	
				.0003	1	
				.0003	3	
				.0008	22	
				.0009	70	
				.0010	237	
				.0012	405	
				.0014	477	
	FE-17	95.0		0	0	
				.0001	1	
				.0001	2	
				.0004	16	
				.0006	65	
				.0007	232	
				.0007	472	
	FE-15	81.0		0	0	
				.0004	1	
				.0005	2	
				.0005	20	
				.0006	260	
			600F	.0006	500	

TABLE XXV CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-6-6-2	LE-14	127	600F	-	0	Failed on Loading
(TUS 121 TYS 97)	LE-15	123		-	0	Failed on Loading
	LE-21	121		-	0	Failed on Loading
	LE-13	120		0	0	
				.0018	1	
				.0027	2	
				.0033	3	
				.0037	4	
				.0086	20	
				.0120	44	
				.0200	140	
				.0223	188	
				.0245	236	
				.0273	308	
				.0349	404	
				.0372	476	
				.0390	572	
				.0407	644	
				.0434	740	
				.0444	812	
				.0457	908	
				.0471	985	Unloaded
	LE-16	117		0	0	
				.0009	1	
				.0012	2	
				.0016	4	
				.0066	93	
				.0072	140	
				.0081	189	
				.0090	261	
				.0104	357	
				.0114	525	
				.0120	597	
				.0123	765	
				.0129	861	
			600F	.0134	937	Unloaded

TABLE XXV CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-6-6-2	LE-18	114.0	600F	0	0	
				.0009	1	
				.0012	2	
				.0014	3	
				.0015	5	
				.0028	41	
				.0040	112	
				.0052	376	
				.0060	616	
	LE-17	112		0	0	
				.0006	1	
				.0008	3	
				.0009	5	
				.0015	24	
				.0024	71	
				.0033	142	
				.0042	310	
				.0054	646	
	LE-20	100.0		0	0	
				.0004	1	
				.0004	2	
				.0006	3	
				.0008	21	
				.0016	94	
				.0020	166	
				.0021	262	
				.0022	430	
			600F	.0024	502	
Ti-6-4 (TUS 93 TYS 73)	AE-2	85	800F	0	0	
				.0037	1	
				.0058	2	
				.0074	3	
				.0089	4	
				.0265	21	
				.0410	45	
				.0425	69	
			800F	.0425	77	Failed

TABLE XXV CREEP TEST SUMMARY (Concluded)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (Hr)	Remarks
Ti-6-4	AE-3	75	800F	0	0	
				.0014	1	
				.0026	2	
				.0032	3	
				.0077	18	
				.0120	43	
				.0183	91	
				.0264	163	
				.0378	259	
				.0431	336	Unloaded
Ti-8-1-1	FE-12	95		0	0	
				.0002	2	
(TUS 99				.0003	20	
TYS 72)				.0012	68	
				.0038	139	Failed
	FE-5	85		0	0	
				.0006	1	
				.0016	18	
				.0028	42	
				.0044	90	
				.0056	162	
				.0070	258	
				.0084	330	Unloaded
	FE-11	72.0		0	0	
				.0003	1	
				.0004	2	
				.0006	3	
				.0007	4	
				.0028	92	
				.0039	260	
				.0043	332	
Ti-6-6-2	LE-8	98		0	0	
				.0190	1	
(TUS 109				.0306	2	
TYS 87)				.0393	3	
				.0474	4	
			800F	.1372	14	Failed

TABLE XXVI RAPID HEAT AND LOAD
CREEP TEST SUMMARY

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (min)	Remarks
Ti-6-4	AE-21	98	600F	0	0	At load
(TUS 101				.0003	1	
TYS 77)				.0009	10	
				.0015	25	
				.0017	40	
				.0017	60	Unloaded
	AE-22	89		0	0	At load
				.0009	5	
				.0013	10	
				.0014	60	Unloaded
	AE-23	79		0	0	At load
				.0002	5	
				.0004	10	
				.0009	15	
				.0012	25	
				.0012	60	Unloaded
	AE-24	71		0	0	At load
				.0012	5	
				.0014	15	
				.0016	20	
				.0017	30	
				.0018	70	
				.0018	80	Unloaded
Ti-8-1-1	FE-16	107		-	-	Failed on loading
(TUS 107 TYS 81)	FE-19	103		0	0	At load
				.0015	5	
				.0018	10	
				.0021	20	
			600F	.0024	34	Failed

TABLE XXVI RAPID HEAT AND LOAD
CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (min)	Remarks
Ti-8-1-1	FE-20	81	600F			
				0	0	At load
(TUS 107				.0004	5	
TYS 81)				.0006	60	Unloaded
Ti-6-6-2	LE-19	119		-	0	Failed on loading
(TUS 121						
TYS 97)	LE-22	112				
				0	0	At load
				.0009	5	
				.0015	10	
				.0018	30	
				.0018	60	Unloaded
	LE-23	100				
				0	0	At load
				.0004	5	
				.0005	10	
				.0006	25	
				.0006	60	Unloaded
	LE-24	90				
				0	0	At load
				.0006	5	
				.0007	10	
				.0008	15	
				.0010	25	
			600F	.0010	60	
Ti-6-4	AE-9	90	800F			
				0	0	At load
(TUS 93				.0027	1	
TYS 73)				.0048	2	
				.0066	3	
				.0081	4	
				.0097	5	
				.0165	10	
				.0335	15	
				.0450	20	
		90	800F	.0585	25	Failed

TABLE XXVI RAPID HEAT AND LOAD
CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (min)	Remarks
Ti-6-4	AE-7	85	800F			
				0	0	At load
(TUS 93				.0007	5	
TYS 73)				.0012	10	
				.0016	15	
				.0019	25	
				.0020	30	
				.0022	35	
				.0025	45	
				.0028	50	
				.0030	60	Unloaded
	AE-10	79				
				0	0	At load
				.0006	5	
				.0012	10	
				.0016	15	
				.0019	20	
				.0021	25	
				.0023	35	
				.0025	40	
				.0027	50	
				.0029	60	Unloaded
	AE-8	75				
				0	0	At load
				.0004	5	
				.0007	10	
				.0012	15	
				.0014	20	
				.0016	25	
				.0018	30	
				.0022	40	
				.0024	45	
				.0026	50	
				.0028	60	Unloaded
	AE-12	65				
				0	0	At load
				.0005	5	
				.0006	10	
				.0007	35	
			800F	.0007	65	Unloaded

TABLE XXVI RAPID HEAT AND LOAD
CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in. in)	Time (min)	Remarks
Ti-6-4	AE-11	58	800F			
				0	0	At load
				.0004	5	
				.0006	10	
				.0008	20	
				.0010	30	
				.0012	35	
				.0012	60	Unloaded
Ti-8-1-1	FE-7	94		-	0	Failed on loading
(TUS 99 TYS 72)	FE-8	85				
				0	0	At load
				.0008	5	
				.0010	10	
				.0014	15	
				.0016	20	
				.0018	45	
				.0020	60	Unloaded
	FE-9	72				
				0	0	At load
				.0003	5	
				.0005	10	
				.0006	25	
				.0007	55	
				.0008	70	Unloaded
	FE-10	58				
				0	0	At load
				.0002	5	
				.0005	10	
				.0006	15	
				.0008	25	
				.0010	40	
			800F	.0010	70	Unloaded

TABLE XXVI RAPID HEAT AND LOAD
CREEP TEST SUMMARY (Continued)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (min)	Remarks
Ti-6-6-2	LE-10	98	800F			
				0	0	At load
(TUS 109				.0014	1	
TYS 8( )				.0028	2	
				.0038	3	
				.0050	4	
				.0059	5	
				.0106	10	
				.0144	15	
				.0178	20	
				.0209	25	
				.0242	30	
				.0275	35	
				.0305	40	
				.0336	45	
				.0366	50	
				.0396	55	
				.0428	60	
				.0456	65	Unloaded
	LE-7	88				
				0	0	At load
				.0015	5	
				.0030	10	
				.0039	15	
				.0048	20	
				.0060	25	
				.0067	30	
				.0075	35	
				.0081	40	
				.0087	45	
				.0090	50	
				.0097	55	
			800F	.0105	60	Unloaded

TABLE XXVI RAPID HEAT AND LOAD
CREEP TEST SUMMARY (Concluded)

Alloy	Specimen ID	Stress (ksi)	Test Temp	Creep Strain (in/in)	Time (min)	Remarks
Ti-6-6-2	LE-9	78	800F			
				0	0	At load
				.0016	5	
				.0028	10	
				.0037	15	
				.0044	20	
				.0052	25	
				.0060	30	
				.0067	35	
				.0070	40	
				.0074	45	
				.0078	50	
				.0082	55	
				.0085	60	Unloaded
	LE-11	69				
				0	0	At load
				.0008	5	
				.0012	10	
				.0016	15	
				.0022	20	
				.0026	25	
				.0032	35	
				.0038	40	
				.0042	45	
				.0044	50	
				.0046	55	
			800F	.0048	60	Unloaded

TABLE XXVII FATIGUE TEST SUMMARY, K_T = 1.0

Range Ratio: R = .1 TEST TEMP.: ROOM
1800 CPM Grain Direction: Longitudinal

Alloy	Specimen Number	TUS (ksi)	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-4	CG-21	145	120	57,630	
	-24		110	59,225	
	-16		100	219,045	
	-23		95	769,125	
	-17		90	1,110,525	
	-18		85	2,582,037	
	-19		80	3,316,840	
	-25		78	8,198,675	
	-20		75	4,811,562	
	CG-22	145	72	17,774,295	
	DK-46	145	130	36,900	
	-47		110	111,780	
	-53		100	809,820	
	-48		90	220,500	
	-51		85	219,780	
	-54		82	88,920	
	-49		80	2,265,000	
	-55		78	7,714,620	
	DK-50	145	75	6,647,400	No Failure
	BK-53	141	120	91,025	
	-47		110	259,500	
	-48		100	1,355,750	
	-54		95	2,542,250	
	-46		90	2,904,700	
	-49		85	3,585,250	
	-55		82	7,989,600	
Ti-6-4	-50	141	78	108,405	

TABLE XXVII FATIGUE TEST SUMMARY, K_T = 1.0 (Continued)

Alloy	Specimen Number	TUS (ksi)	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-4	BK-51	141	78	353,405	
	BK-52	141	76	10,039,500	
	EM-11	142	120	34,177	Heavy Extr
	-12		95	982,632	Heavy Extr
	-13		76	3,512,105	Heavy Extr
	-14		72	290,280	Heavy Extr
	EM-15	142	72	10,607,900	Heavy Extr
Ti-6-4	HG-24	133	130	25,020	
Ti-8-1-1	-23		105	479,700	
	-16		100	822,960	
	-17		97	792,180	
	-18		90	54,360	
	-21		88	677,160	
	-25		87	1,293,300	
	-19		85	6,845,000	
	HG-20	133	82	10,083,600	No Failure
	JK-46	134	110	105,540	
	-47		100	90,930	
	-48		90	1,734,500	
	-49		85	3,678,000	
	-50		82	1,045,350	
	-51		80	1,768,880	
	-54		77	6,349,860	
	-53		75	9,160,900	
	JK-55	134	72	8,554,700	
	GK-48	140	120	157,866	
	-46		110	445,000	
	-53		105	638,750	
Ti-8-1-1	-51	140	100	71,000	

TABLE XXVII FATIGUE TEST SUMMARY, K_T = 1.0 (Continued)

Alloy	Specimen Number	TUS (ksi)	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti8Al-1Mo-1V	GK-52	140	95	1,286,010	
	-47		90	1,159,860	
	-49		85	2,004,750	
	-54		82	1,969,680	
	-50		81	14,170,750	No Failure
	GK-55	140	75	13,345,700	
	KM-11	139	120	101,723	Thick Extr
	-12		100	54,390	Thick Extr
	-14		90	212,440	Thick Extr
	-13		80	2,541,500	Thick Extr
	KM-15	139	75	1,786,640	Thick Extr
Ti6Al-6V-2Sn	NG-18	147	120	77,040	
	-19		110	429,300	
	-25		100	719,100	
	-21		95	854,820	
	-23		92	2,823,840	
	-16		90	3,631,680	
	-24		88	1,601,280	
	-17		85	455,400	
	-22		83	8,527,320	
	NG-20	147	80	10,144,800	No Failure
	FK-51	145	120	93,250	
	-49		100	583,560	
	-53		95	1,831,860	
	-52		90	2,456,820	
	-54		85	1,738,800	
	-55		80	2,404,800	
	-50		78	9,237,600	
	-47		75	4,053,900	
Ti-6-6-2	FK-48	145	73	11,780,000	No Failure

TABLE XXVII FATIGUE TEST SUMMARY, K_T = 1.0 (Concluded)

Alloy	Specimen Number	TUS (ksi)	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-6-2	MK-48	157	120	258,660	
	-47		110	414,900	
	-46		100	987,660	
	-50		95	847,080	
	-49		90	3,472,560	
	-55		88	5,279,940	
	-54		87	10,000,000	No Failure
	-51		85	6,570,720	
	MK-52	157	82	18,243,000	No Failure
	RM-11	155	120	41,760	Thick Extr
	-15		110	448,610	Thick Extr
	-12		95	2,297,240	Thick Extr
	-14		90	2,844,180	Thick Extr
Ti-6-6-2	RM-13	155	82	4,830,920	Thick Extr

TABLE XXVIII FATIGUE TEST SUMMARY, K_T = 2.76, ROOM TEMPERATURE

(Grain Direction: Longitudinal)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-4	CG-3	-1.0	50	44,798	
	DK-2		50	48,825	
	BK-5		50	22,320	
	DK-3		40	71,145	
	BK-2		40	287,560	
	CG-1		35	509,400	
	DK-1		35	501,500	
	DK-4		30	1,[illegible]84,000	
	BK-3		30	6,415,700	
	CG-2		29	6,112,000	
	CG-5		26	5,600,000	
	DK-5	-1.0	26	6,460,000	
	CG-9	+ .01	80	23,760	
	BK-19		80	19,440	
	DK-17		70	28,426	
	CG-6		65	65,600	
	DK-19		60	39,322	
	BK-16		60	532,260	
	CG-10		55	695,700	
	DK-16		50	838,780	
	BK-17		50	1,895,550	
	BK-18		46	2,567,800	
	CG-7		45	2,256,300	
	DK-18		45	3,931,200	
	BK-20		42	3,000,000	
	DK-20		41	797,580	
	CG-8	+ .01	40	2,611,300	
	DK-31	+ .43	93	39,060	
	CG-13		80	399,600	
	BK-33		80	52,740	
	DK-32		75	129,600	
	CG-11		71	77,040	
	BK-34		70	1,258,820	
	CG-12		60	2,937,200	
	DK-33		60	1,353,900	
	BK-31		60	3,827,100	
	CG-14		57	1,429,500	
	BK-32		56	5,196,500	
	BK-35		55	8,243,100	
Ti-6-4	CG-15	+ .43	54	5,770,000	

TABLE XXVIII FATIGUE TEST SUMMARY, K_T = 2.76, ROOM TEMPERATURE (Continued)

(Grain Direction: Longitudinal)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-8-1-1	HG-4	-1.0	50	19,980	
	GK-1		50	23,460	
	JK-2		45	39,420	
	GK-4		40	48,600	
	HG-1		35	216,180	
	JK-1		35	110,700	
	GK-2		35	1,510,900	
	GK-3		32	1,715,900	
	JK-4		30	1,816,500	
	HG-2		29	2,793,600	
	GK-5		29	2,638,800	
	HG-5		27	3,788,100	
	JK-3		26	1,220,100	
	HG-3		25	10,776,600	No Failure
	JK-5	-1.0	23	10,900,000	No Failure
	JK-18	+ .01	80	27,940	
	HG-8		7[illegible]	33,120	
	GK-19		75	37,800	
	HG-10		65	27,000	
	JK-16		65	55,965	
	GK-20		65	485,770	
	GK-17		60	587,770	
	HG-6		50	216,470	
	JK-17		50	663,480	
	GK-16		50	1,187,400	
	HG-7		45	1,595,570	
	JK-19		42	944,640	
	HG-9		40	11,580,000	No Failure
	JK-20	+ .01	36	10,700,000	No Failure
	HG-13	+ .43	90	70,560	
	GK-35		90	47,160	
	JK-33		85	26,230	
	GK-33		80	162,330	
	GK-34		75	378,540	
	HG-11		70	394,000	
	HG-12		65	1,125,700	
	JK-32		65	340,000	
	HG-14		62	2,404,600	
	JK-35		60	655,900	
	GK-31		60	10,000,000	No Failure
Ti-8-1-1	HG-15	+ .43	58	9,320,000	No Failure

TABLE XXVIII FATIGUE TEST SUMMARY, K_T = 2.76, ROOM TEMPERATURE (Concluded)
(Grain Direction: Longitudinal)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-6-2	PK-2	-1.0	45	52,095	
	NG-1		40	25,012	
	NG-4		35	134,460	
	PK-1		35	240,040	
	MK-3		35	595,200	
	NG-2		30	499,980	
	PK-4		30	1,405,000	
	MK-4		30	7,399,000	
	PK-5		28	1,693,000	
	PK-3		25	10,152,000	No Failure
	NG-3	-1.0	25	11,130,000	No Failure
	NG-8	+ .01	75	27,000	
	PK-19		75	30,960	
	MK-18		70	25,920	
	NG-6		60	329,580	
	PK-17		60	48,240	
	MK-19		60	353,700	
	NG-7		50	2,536,200	
	PK-16		50	833,940	
	MK-17		50	1,800,000	
	PK-18		45	3,608,400	
	NG-10		45	13,636,800	No Failure
	MK-20		44	11,914,000	No Failure
	PK-20		42	10,000,000	No Failure
	MK-16	+ .01	40	7,506,000	No Failure
	NG-14	+ .43	90	37,080	
	MK-32		85	28,620	
	NG-15		80	81,540	
	PK-32		80	36,900	
	MK-35		80	801,000	
	NG-11		75	895,500	
	MK-33		75	746,860	
	PK-31		70	46,800	
	MK-31		70	3,643,200	
	NG-12		67	1,036,600	
	MK-34		67	10,000,000	No Failure
Ti-6-6-2	NG-13	+ .43	64	1,566,180	

1. K_T Based on Net Areas
2. Range Ratio R = Minimum Stress/Maximum Stress

TABLE XXIX FATIGUE TEST SUMMARY, $K_T = 2.76$

Test Temperature: 400°F
Grain Direction: Longitudinal

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-4	BK-7	-1.0	45	16,920	
	DK-6		40	56,832	
	DK-9		35	66,040	
	BK-6		35	40,500	
	BK-9		33	63,720	
	DK-7		30	519,400	
	BK-8		30	3,129,400	
	BK-10		27	2,008,200	
	DK-10	-1.0	25	1,372,500	
	DK-22	+ .01	65	23,220	
	BK-23		61	42,122	
	DK-21		55	37,620	
	BK-24		50	1,809,300	
	BK-25		46	1,371,600	
	DK-23		45	1,658,800	
	DK-24		42	5,104,700	
	DK-25	+ .01	40	3,983,200	
Ti-6-4	BK-37	+ .43	80	19,440	

TABLE XXIX FATIGUE TEST SUMMARY, $K_T = 2.76$ (Continued)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-4	BK-38	+ .43	72	391,320	
	DK-36		70	34,920	
	BK-36		65	528,900	
	BK-40		63	1,854,000	
	DK-37		60	880,740	
	DK-40		47	10,253,300	No Failure
Ti-6-4	DK-39	+ .43	45	11,043,000	No Failure
Ti-8-1-1	GK-6	-1.0	45	29,260	
	JK-6		40	18,012	
	JK-7		30	2,182,400	
	GK-7		30	1,131,170	
	JK-8		27	1,273,100	
	JK-10		25	1,586,500	
	GK-9	-1.0	25	10,000,000	No Failure
	GK-22	+ .01	65	23,708	
	JK-21		60	50,837	
	JK-25		55	109,980	
	GK-24		55	353,700	
	JK-22		50	357,180	
Ti-8-1-1	GK-21	+ .01	50	393,120	

TABLE XXIX FATIGUE TEST SUMMARY, K_T = 2.76 (Continued)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-8-1-1	JK-23	+ .01	47	103,020	
	GK-23		45	12,585,500	
	JK-24	+ .01	40	7,530,240	
	GK-37	+ .43	80	287,460	
	JK-37		75	92,700	
	GK-38		75	202,680	
	JK-36		65	1,691,200	
	GK-36		65	1,007,100	
	JK-40		63	2,674,800	
	GK-40		60	2,050,900	
Ti-8-1-1	JK-39	+ .43	58	13,402,800	No Failure
Ti-6-6-2	MK-9	-1.0	50	16,790	
	MK-7		40	1,532,500	
	PK-7		30	33,320	
	MK-6		30	4,808,700	
	PK-10		28	1,963,900	
	PK-8		25	3,120,300	
	PK-9	-1.0	22	10,504,000	No Failure
Ti-6-6-2	MK-24	+ .01	70	30,960	

TABLE XXIX FATIGUE TEST SUMMARY, K_T = 2.76 (Concluded)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-6-2	PK-22	+ .01	67	22,140	
	PK-23		55	400,640	
	MK-21		50	475,920	
	PK-24		46	552,500	
	MK-23		46	1,658,500	
	MK-25		42	18,478,200	No Failure
	PK-25	+ .01	40	1,182,300	
	MK-39	+ .43	90	26,460	
	MK-37		80	659,160	
	MK-36		75	882,900	
	PK-36		70	52,200	
	MK-38		70	1,896,800	
	MK-40		67	842,760	
	PK-38		62	68,220	
	PK-40		60	7,894,600	
	PK-37		55	5,785,500	
Ti-6-6-2	PK-39	+ .43	50	8,649,500	

TABLE XXX FATIGUE TEST SUMMARY K_T = 2.76, 600°F

(Grain Direction: Longitudinal)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-6-4	DK-13	-1.0	40	23,800	
	BK-15		40	22,120	
	DK-12		30	711,180	
	BK-11		30	2,569,800	
	DK-14		25	3,533,800	
	BK-12		25	1,808,500	
	BK-14		23	3,252,400	
	DK-15	-1.0	20	3,456,000	
	BK-27	+ .01	78	14,766	
	DK-27		62	14,400	
	DK-26		55	287,270	
	BK-29		50	45,720	
	BK-26		51	991,430	
	DK-28		48	1,714,600	
	BK-28		45	78,840	
	DK-29		43	2,356,500	
	DK-30		40	4,001,900	
	BK-30	+ .01	35	10,000,000	No Failure
	BK-43	+ .43	75	34,560	
	DK-42		70	43,740	
	DK-44		65	3,176,600	
	BK-41		65	1,860,700	
	DK-41		60	2,475,500	
	BK-42		60	337,500	
	DK-45		55	10,000,000	No Failure
	BK-44		53	3,156,300	
Ti-6-4	BK-45	+ .43	50	12,702,600	No Failure
Ti-8-1-1	GK-12	-1.0	40	28,860	
	JK-11		35	25,560	
	GK-11		30	446,110	
	JK-14		28	731,160	
	GK-15		26	2,088,700	
	JK-15		24	3,511,400	
	GK-14	-1.0	24	10,386,000	No Failure
	JK-26	+ .01	60	44,415	
	JK-29		55	208,580	
	GK-26		50	794,000	
	JK-27		45	1,208,500	
Ti-8-1-1	GK-28	+ .01	45	205,000	

TABLE XXX FATIGUE TEST SUMMARY K_T = 2.76, 600°F (Continued)

(Grain Direction: Longitudinal)

Alloy	Specimen Number	Range Ratio	Max Stress Net Area (ksi)	Cycles To Failure	Remarks
Ti-8-1-1	GK-29	+0.01	42	2,304,900	
	JK-28		40	8,229,300	
	JK-30		38	4,847,300	
	GK-30	+0.01	37	10,292,500	No Failure
	GK-45	+0.43	90	22,860	
	GK-43		80	312,750	
	JK-42		75	55,620	
	JK-43		72	176,820	
	GK-41		70	637,970	
	JK-41		65	1,136,200	
	GK-42		63	683,350	
	JK-44		60	761,000	
	GK-44		57	10,000,000	No Failure
Ti-8-1-1	JK-45	+0.43	56	10,000,000	No Failure
	PK-12	-1.0	40	35,520	
Ti-6-6-2	MK-15		40	163,020	
	PK-15		35	417,180	
	PK-11		30	436,850	
	MK-11		30	1,080,200	
	PK-13		26	6,086,800	
	MK-14		25	15,528,000	No Failure
	PK-14	-1.0	24	10,310,000	No Failure
	MK-28	+0.01	65	42,282	
	PK-26		60	28,080	
	MK-30		60	239,180	
	PK-28		50	127,260	
	MK-26		50	383,220	
	MK-27		45	2,175,000	
	PK-27		43	3,586,500	
	MK-29		42	10,000,000	No Failure
	PK-30		40	10,000,000	No Failure
	PK-29	+0.01	38	12,760,000	No Failure
	MK-44	+0.43	90	10,800	
	PK-43		80	23,400	
	MK-42		80	356,220	
	PK-41		78	11,000	
	PK-42		70	2,397,700	
	MK-41		70	3,004,900	
Ti-6-6-2	MK-45	+0.43	63	2,366,200	

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) LOCKHEED-CALIFORNIA COMPANY BURBANK, CALIFORNIA	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP

6 DEVELOPMENT OF ENGINEERING DATA ON TITANIUM EXTRUSION FOR USE IN AEROSPACE DESIGN.

9 SUMMARY TECHNICAL REP[redacted]T. 27 Jun 66-31 May 67,

10 R.M. BROCKETT [redacted]
A. GOTTBRATH [redacted]

11 Jul [redacted] 67 12 220p.	7a. TOTAL NO. OF PAGES 195	7b. NO. OF REFS
15 AF33(615)-5080 16 AF-7381 c. 17 738106 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 18 AFML 19 TR-67-189 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY AIR FORCE MATERIALS LABORATORY, RTD, AIR FORCE SYSTEMS COMMAND WRIGHT PATTERSON AFB, OHIO

13. ABSTRACT

Mechanical property data for Ti6Al-4V, Ti8Al-1Mo-1V and Ti6Al-6V-2Sn extruded shapes in annealed tempers were obtained at test temperatures from -110°F to +800°F to provide a base for development of design information for these materials. Data obtained included ultimate tensile strength, tensile yield strength, compressive yield strength, shear bearing, impact properties, creep, stress-rupture, fatigue and fracture toughness characteristics.

Separate heats of material in each of the three alloys were obtained from separate suppliers. Two section sizes were obtained from one of the suppliers to provide information on size effects. Tests conducted to provide data insofar as practicable within the scope of this program on property variations and on scatter.

Results of testing indicate that with consideration of effect of temperatures used in extrusion processing, extrusions may be utilized in the same manner as titanium materials produced by other methods such as rolling or forging. Data obtained generally indicates that extruded material may be expected to have not only the cost advantages which result from economy of shape design, but will possess advantages in developed fracture characteristics and creep characteristics when compared with conventional alpha-beta processing of rolled or forged materials.

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